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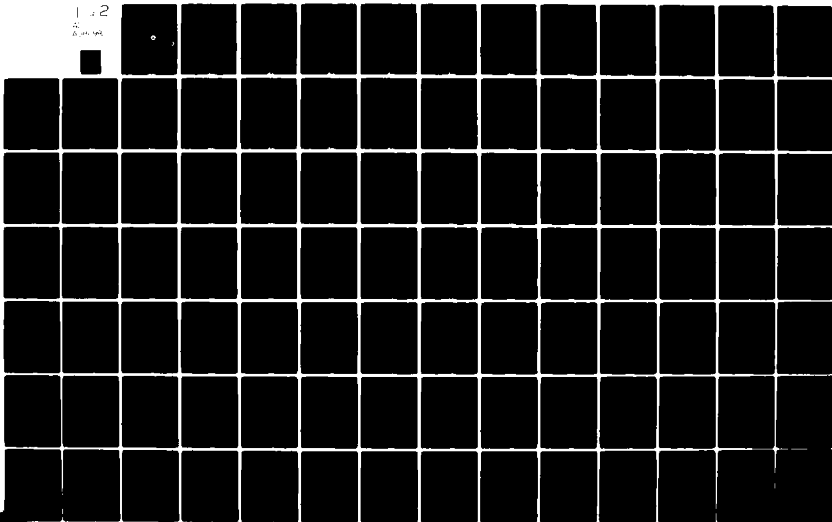

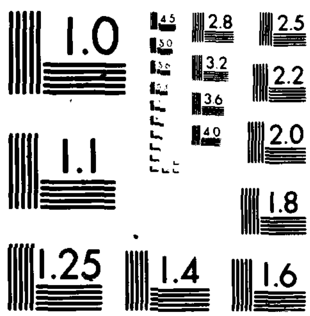

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LEVEL II

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VORTEX ADVISORY SYSTEM
Volume I: Effectiveness for Selected Airports

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J.N. Hallock

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

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16. Abstract

The Vortex Advisory System (VAS) is based on a wind criterion; when the wind near the runway end is outside of the criterion, all interarrival Instrument Flight Rules (IFR) aircraft separations can be set at 3 nautical miles. Five years of wind data have been obtained for 20 airports. By comparing the VAS wind criterion to the 5 years of wind data, the percentages of time that interarrival separations can be reduced at the 20 airports have been found. The percentages are given on an hourly and a monthly basis.

Volume II (to be published at a later date) will examine the VAS effectiveness at Chicago O'Hare (ORD) with respect to the length of the intervals during which reduced separations might have been used.

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PREFACE

The concept of a Vortex Advisory System (VAS) evolved from the analysis of tens of thousands of vortex tracks. Wind velocity was found to be the primary determinant of vortex behavior. The VAS uses wind-velocity measurements to indicate when interarrival separations can be reduced. This study examines historical wind data to permit estimates of the utility of a VAS if the system is installed at the 20 airports considered herein.

We wish to acknowledge the assistance of Robert Crosby, System Development Corporation, who programmed the calculations and ran the numerous cases. We also thank Myron Clark, FAA, and Thomas Sullivan, TSC, for their suggestions and comments in the preparation of this volume of the report.

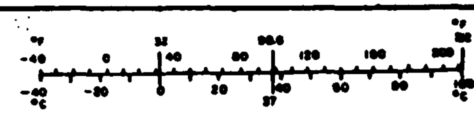
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Before 1970, landing aircraft were required to maintain at least 3-nautical-mile separations under Instrument Flight Rules (IFR) conditions. The interarrival separation standard was based primarily on radar-operating limits and, to a lesser extent, on runway-occupancy limitations. With the introduction of the wide-body jets and the ever increasing number of aircraft operations at the major airports, the potential danger of encountering a wake vortex became more apparent.

Accordingly, the Federal Aviation Administration (FAA) in March 1970 increased the separation standards behind Heavy jets (a Heavy jet has a maximum certificated takeoff weight of at least 300,000 pounds) evolving by 1973 to 5 nautical miles for a following non-Heavy aircraft. The interarrival standards were revised in November 1975 by the addition of another nautical-mile separation at threshold for a following Small aircraft (a Small aircraft has a maximum certificated takeoff weight of less than 12,500 pounds) behind a Heavy or Large aircraft (a Large aircraft has a maximum certificated takeoff weight between 12,500 and 300,000 pounds). These increased separations led to additional delays and decreased the capacity and throughput of the airport system.

The constriction of capacity due to wake-vortex imposed separations is a major contributor to traffic delays (Ref. 1). Many of the high density terminals are currently operations-saturated during periods of peak traffic causing costly delays to passengers and airlines, especially during this period of escalating fuel costs.

The Vortex Advisory System (VAS) has been developed to regain some of the lost capacity. The VAS indicates to controllers when separation standards could be reduced to the pre-March 1970 standard of 3 nautical miles regardless of the leader or follower aircraft type.

The VAS evolved from the detailed study of vortex tracks from approximately 70,000 aircraft, and the correlation of vortex behavior with the ambient winds. Analysis showed that a wind-rose criterion could be used to determine when interarrival separations might be reduced uniformly to 3 nautical miles (Refs. 2 through 6). Usually, vortices either transported away or decayed to an innocuous level. It was found that 1-minute-averaged winds could be used to predict when vortices would not persist near the extended runway centerline. Whenever the wind exceeds a wind-rose criterion, uniform 3-nautical-mile spacings may be used safely. None of the vortices studied would have posed a safety problem even if all interarrival spacings were 3 nautical miles during the time when the wind exceeded the wind-rose criterion.

The VAS has been designed (Refs. 2 and 7) to use the wind-rose criterion. The system compares the measured 1-minute-averaged wind magnitude and direction (with respect to the runway heading) with the wind-rose criterion. The result of the comparison is indicated to an air traffic controller via a simple display; a green light means that 3-nautical-mile spacings may be used for aircraft conducting precision approaches, and a red light means that the normal 3-, 4-, 5-, or 6-nautical-mile spacing should be used during IFR depending on the respective aircraft types.

The wind criterion takes the form of the ellipse (with a semi-major axis of 12.5 knots, aligned with the runway heading; the semi-minor axis is 5.5 knots), which is shown in Figure 1. Based on the study of the vortices, it is asserted that whenever the wind was found to be outside the ellipse, there was no vortex observed which would have precluded using 3-nautical-mile spacings safely for all aircraft. The objective of this study is to answer the question: "How often does the wind at a particular airport exceed the wind-rose or VAS-ellipse criterion?" Further, the results will establish the utility of a VAS at each of the 20 selected airports in the report.

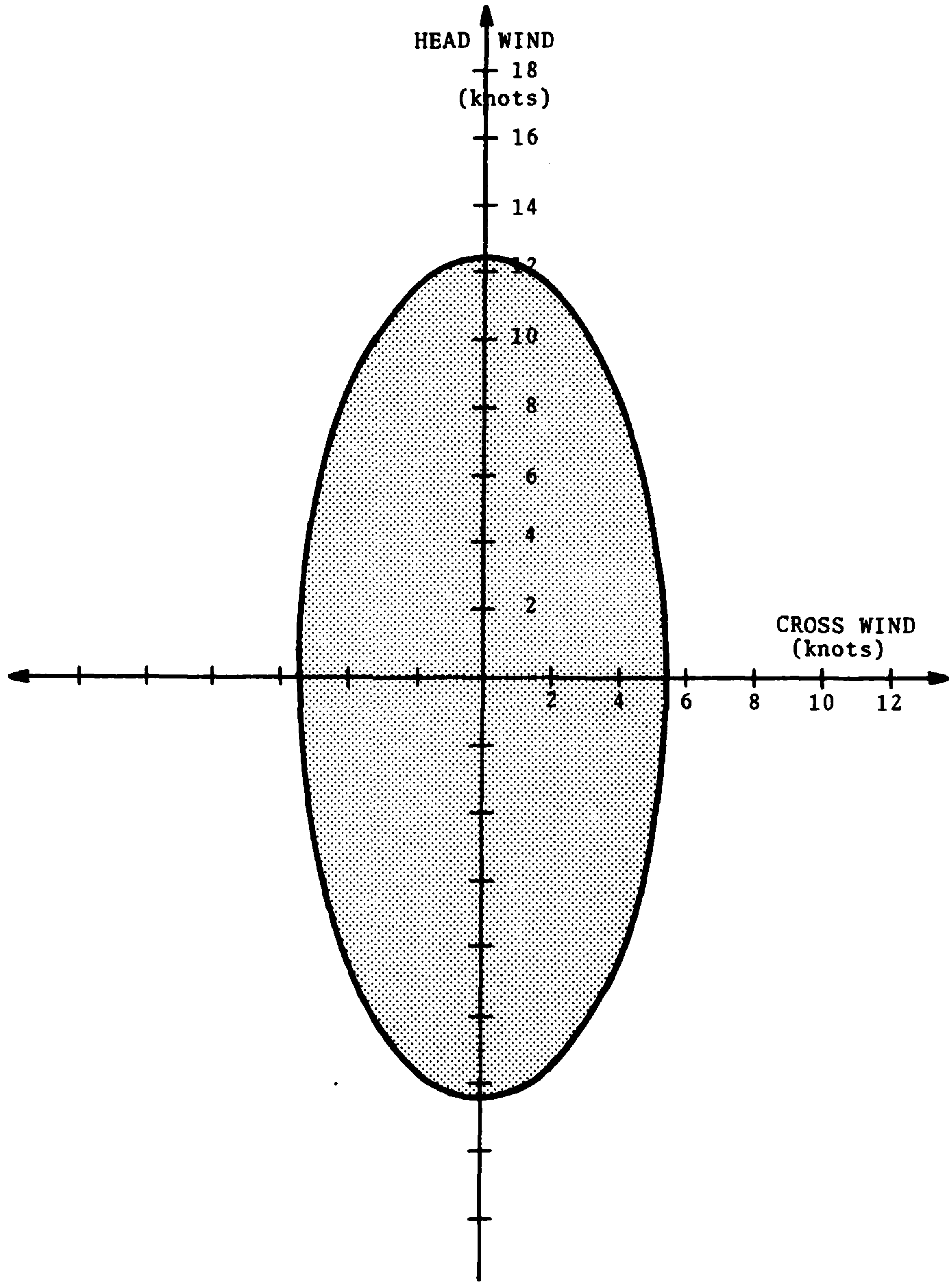


FIGURE 1. VAS ELLIPTICAL WIND CRITERION

Section 2 introduces the term used to measure how often the winds are outside the VAS-elliptical criterion. Section 3 presents the calculations for the 20 airports. Section 4 comments on extending these calculations, and briefly summarizes the report.

2. EFFECTIVENESS

The term "effectiveness" is a measure of the percentage of time that the wind velocity exceeds the wind-rose or elliptical VAS criterion. In other words, "effectiveness" is a measure of how often the uniform 3-nautical-mile interarrival separations can be employed. This does not refer to the effectiveness of the VAS itself since no consideration is given to traffic levels, traffic mixes, and the number of available runways.

The usefulness of the VAS is dependent on (a) the frequency of green lights, (b) the length of their intervals, (c) their correlation with peaks in the traffic demand, and (d) their correlation with IFR arrivals. This report addresses the first dependence (a) by examining the VAS effectiveness on a diurnal and monthly basis. The length of the green-light intervals (b) is the subject of Volume II of this report. Section 3 examines (c). To date, (d) has not been considered directly; there are strong indications that the overall wind data discussed herein are representative of the wind during IFR days.

2.1 WIND DATA

The wind data were obtained from the National Climatic Center, in Ashville, North Carolina, which is a part of the National Oceanic and Atmospheric Administration. The wind velocity was recorded every 3 hours. These data were obtained for 20 airports for the 5-year period from January 1972 through December 1976 on 9-track, EBCDIC, 800 bpi magnetic tape.

The wind measurements correspond to 1-minute-averaged surface observations which were manually recorded 10 minutes before the hour on Meteorological Forms 1-10A and 1-10B by the National Weather Service (NWS) personnel at the various airports. The times are always Local Standard Times. The wind direction is recorded in tens of degrees measured with respect to True North; the wind speed is given to the nearest knot.

The NWS sensor is usually located near the center of the airport in an unobstructed area. The sensor is the standard F-420 cup-and-vane type which is about 30 feet above the ground.

2.2 VAS ELLIPSE

The relevant wind-rose criterion is the ellipse shown in Figure 1. However, when the wind is at the edge of the ellipse (for instance, a 5.5-knot crosswind), a small increase/decrease in wind magnitude causes the VAS lights to change state (green to red, or red to green) often. Rapid changes lead to extreme difficulties for the air traffic controller.

To avoid these rapid changes, the mechanization of the VAS incorporated a guard band surrounding the VAS ellipse. Figure 2 shows a 2-knot guard band about the VAS ellipse. Thus, instead of displaying a green light once the wind is outside the VAS ellipse (the inner ellipse), hysteresis has been introduced. The wind must now increase from inside the inner ellipse to outside the outer ellipse before the light changes from red to green. The light will change back to red whenever the 1-minute-averaged wind falls back to inside the inner ellipse.

To calculate the effectiveness without the guard band, the wind data are merely compared with a given runway heading and disaggregated into either outside or inside the ellipse. The percent effectiveness is simply the percentage of the data falling outside the ellipse. The institution of the guard band alters the calculation somewhat. If the wind vector is between the two ellipses, the wind may be either increasing toward the outer ellipse, or decreasing toward the inner VAS ellipse. It is expected that these two situations are equally probable. Thus, the percent effectiveness is given by the percentage of the data falling outside the outer ellipse plus one-half of the percentage of the data falling between the two ellipses.

The calculations in Section 3 are all based on a 2-knot guard band. Section 4.1 indicates the method for scaling the results of Section 3 for any guard-band size.

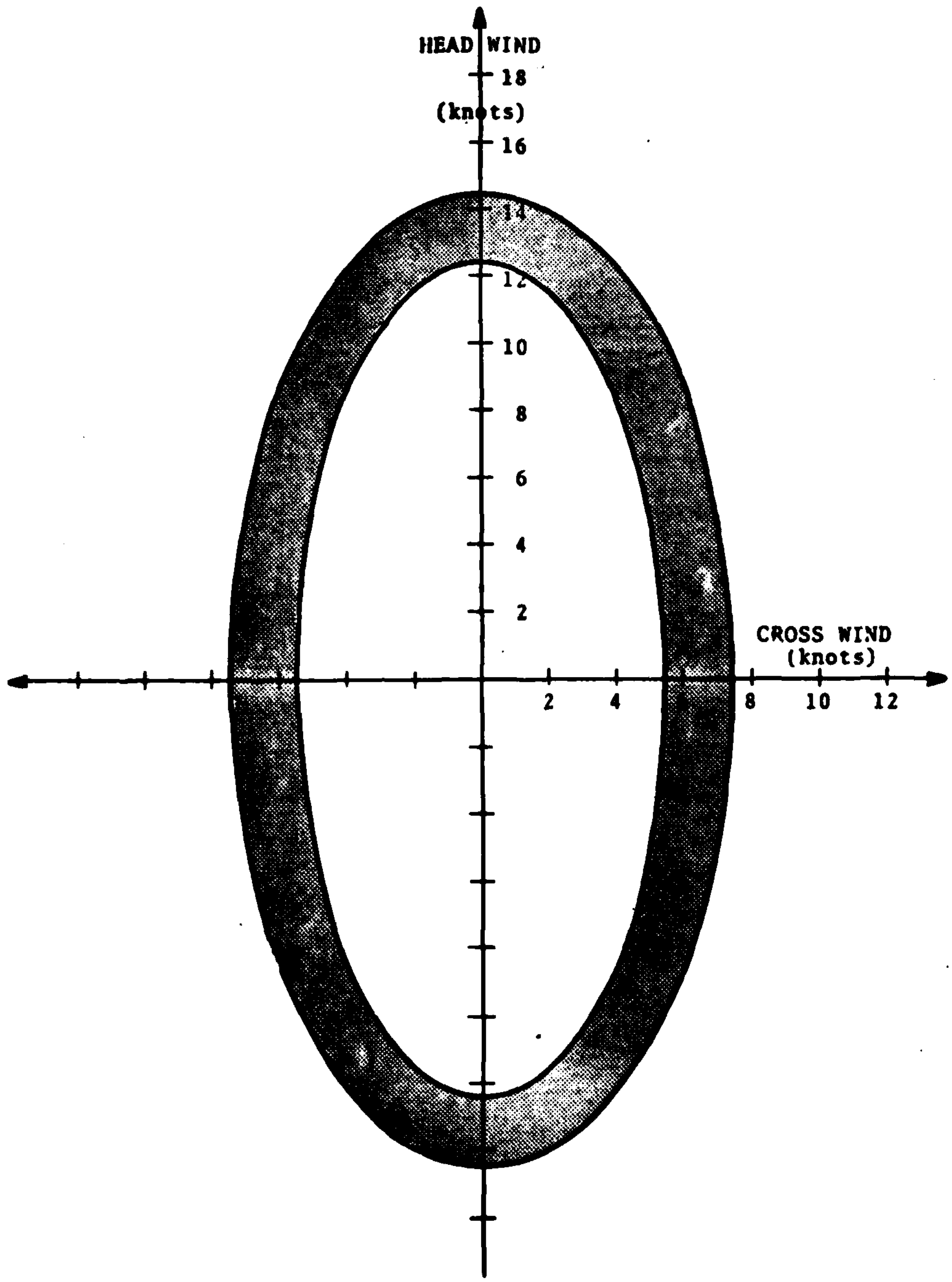


FIGURE 2. VAS WIND CRITERION WITH 2-KNOT GUARD BAND

2.3 AIRPORTS AND RUNWAYS

A cost/benefits study of 15 airports (Ref. 8) has identified 11 with a VAS implementation benefit-to-cost ratio greater than unity. The top 20 air carrier airports are addressed herein, and are given in Table 1. For convenience, the three-letter airport code will be used throughout the remainder of the report.

For a runway to be considered for instrumenting with a VAS, the runway must be equipped with an Instrument Landing System (ILS). Reference 2 examines the restriction to precision approaches during VAS operations. Table 2 lists the major runways at the 20 airports considered herein.

TABLE 1. AIRPORTS

CODE	NAME	LOCATION
ORD	Chicago-O'Hare International	Chicago IL
ATL	William B. Hartsfield Atlanta Int'l	Atlanta GA
BOS	Logan International	Boston MA
DCA	Washington National	Washington DC
DEN	Stapleton International	Denver CO
DFW	Dallas-Fort Worth Regional	Dallas-Ft Worth TX
DTW	Detroit Metropolitan Wayne County	Detroit MI
JFK	John F. Kennedy International	New York NY
LAX	Los Angeles International	Los Angeles CA
LGA	LaGuardia	New York NY
MIA	Miami International	Miami FL
MSP	Minneapolis-St. Paul International	Minneapolis MN
SEA	Seattle-Tacoma International	Seattle WA
SFO	San Francisco International	San Francisco CA
TPA	Tampa International	Tampa FL
CLE	Cleveland-Hopkins International	Cleveland OH
EWR	Newark International	Newark NJ
PHL	Philadelphia International	Philadelphia PA
PIT	Greater Pittsburgh International	Pittsburgh PA
STL	Lambert-St. Louis International	St. Louis MO

TABLE 2. RUNWAYS

AIRPORT	RUNWAY	LENGTH/WIDTH (feet/feet)	ILS
ORD	4L/22R	7500/150	Yes
	4R/22L	8071/150	Yes
	9L/27R	7416/150	Yes
	9R/27L	10141/150	Yes
	14L/32R	10003/150	Yes
	14R/32L	11600/200	Yes
	18/36	5341/150	No
ATL	8/26	10000/150	Yes
	9L/27R	8000/150	No
	9R/27L	9000/150	Yes
BOS	4L/22R	7860/150	No
	4R/22L	10001/150	Yes
	9/27	7000/150	No
	15L/33R	2468/125	No
	15R/33L	10081/150	Yes
DCA	3/21	4724/150	No
	15/33	5212/200	No
	18/36	6870/200	Yes
DEN	7/25	5020/75	No
	8L/26R	7926/150	No
	8R/26L	10004/150	Yes
	17L/35R	12000/200	Yes
	17R/35L	11500/150	Yes
	17C/35C	6480/100	No
DFW	13L/31R	9000/200	Yes
	17L/35R	11387/200	Yes
	17R/35L	11387/200	Yes
DTW	3L/21R	10500/200	Yes
	3C/21C	8500/200	No
	9/27	8702/200	Yes
JFK	4L/22R	11351/150	Yes
	4R/22L	8400/150	Yes
	13L/31R	10001/150	Yes
	13R/31L	14572/150	Yes
	14/32	2762/75	No
LAX	6L/24R	8925/150	Yes
	6R/24L	10285/150	Yes
	7L/25R	12090/150	Yes
	7R/25L	12000/200	Yes
	8/26	3000/75	No

TABLE 2. RUNWAYS (CONT.)

AIRPORT	RUNWAY	LENGTH/WIDTH (feet/feet)	ILS
LGA	4/22	6999/150	Yes
	13/31	6999/150	Yes
	14/32	2000/75	No
MIA	9L/27R	10500/200	Yes
	9R/27L	9350/150	Yes
	12/30	9601/150	No
MSP	4/22	8268/150	Yes
	11L/29R	8201/150	Yes
	11R/29L	10000/200	Yes
SEA	16L/34R	11900/150	Yes
	16R/34L	9424/150	Yes
	17/35	2750/75	No
SFO	1L/19R	7000/200	No
	1R/19L	9500/200	Yes
	10L/28R	11870/200	Yes
	10R/28L	10600/200	Yes
TPA	9/27	7000/150	No
	18L/36R	8300/150	Yes
	18R/36L	8700/150	Yes
CLE	5L/23R	6242/200	No
	5R/23L	9000/150	Yes
	10L/28R	6014/150	Yes
	10R/28L	3276/75	No
	18L/36R	5015/150	No
	18R/36L	6411/150	No
EWR	4L/22R	8199/150	Yes
	4R/22L	9810/150	Yes
	11/29	6796/150	No
PHL	9L/27R	9500/150	Yes
	9R/27L	10499/200	Yes
	17/35	5459/150	No
PIT	10L/28R	10502/150	Yes
	10C/28C	10101/150	Yes
	14/32	8101/150	Yes
	5/23	3939/150	No

TABLE 2. RUNWAYS (CONT.)

AIRPORT	RUNWAY	LENGHT/WIDTH (feet/feet)	ILS
STL	6/24	7602/200	Yes
	12L/30R	6621/150	No
	12R/30L	10018/200	Yes
	17/35	6000/150	No

3. EFFECTIVENESS VALUES

To calculate the effectiveness of the VAS, the dual elliptical wind criterion is aligned with the direction of the runway heading (e.g., the semi-major axis is aligned with the runway heading) and the number of 3-hourly datum points falling (a) within the inner ellipse (VAS red), (b) outside the outer ellipse (VAS green), and (c) between the two ellipses are totaled, respectively. The percentage effectiveness is, as defined earlier, the percentage outside the outer ellipse (b) plus one-half the percentage between the two ellipses (c).

This section addresses the effectiveness values for the 20 airports viewed on a monthly and an hourly basis. For the reader's convenience, the graphs for Chicago O'Hare are shown and discussed within Section 3.1, and all the other graphs for the 19 airports are collected at the end of the section.

3.1 CHICAGO-O'HARE INTERNATIONAL AIRPORT

Chicago O'Hare (ORD) has three sets of parallel runways (4/22, 9/27, and 14/32) and a short runway usually reserved for general aviation (18/36). The calculations consider 4L/22R and 4R/22L as one runway (and similarly for all other parallel runways).

Figure 3 shows the effectiveness on ORD runway 4/22 by month (top graph) and by hour (bottom graph). The solid lines are only for guidance. As an example, the 60-percent effectiveness indicated for February is an average over the eight 3-hourly readings for each day in February for the 5 years from 1972 to 1976 (142 days) or a total of 1136 readings. Similarly, the 59-percent effectiveness for 1500 hours Local Time is an average over the wind data recorded at 1500 hours, a total of 1872 readings.

Figure 4 shows the effectiveness on runway 4/22 by month and hour. The 40-percent effectiveness for April at midnight is an average of the 30 days in April for the 5-year period; the 40-percent effectiveness is an average of 150 separate effectiveness

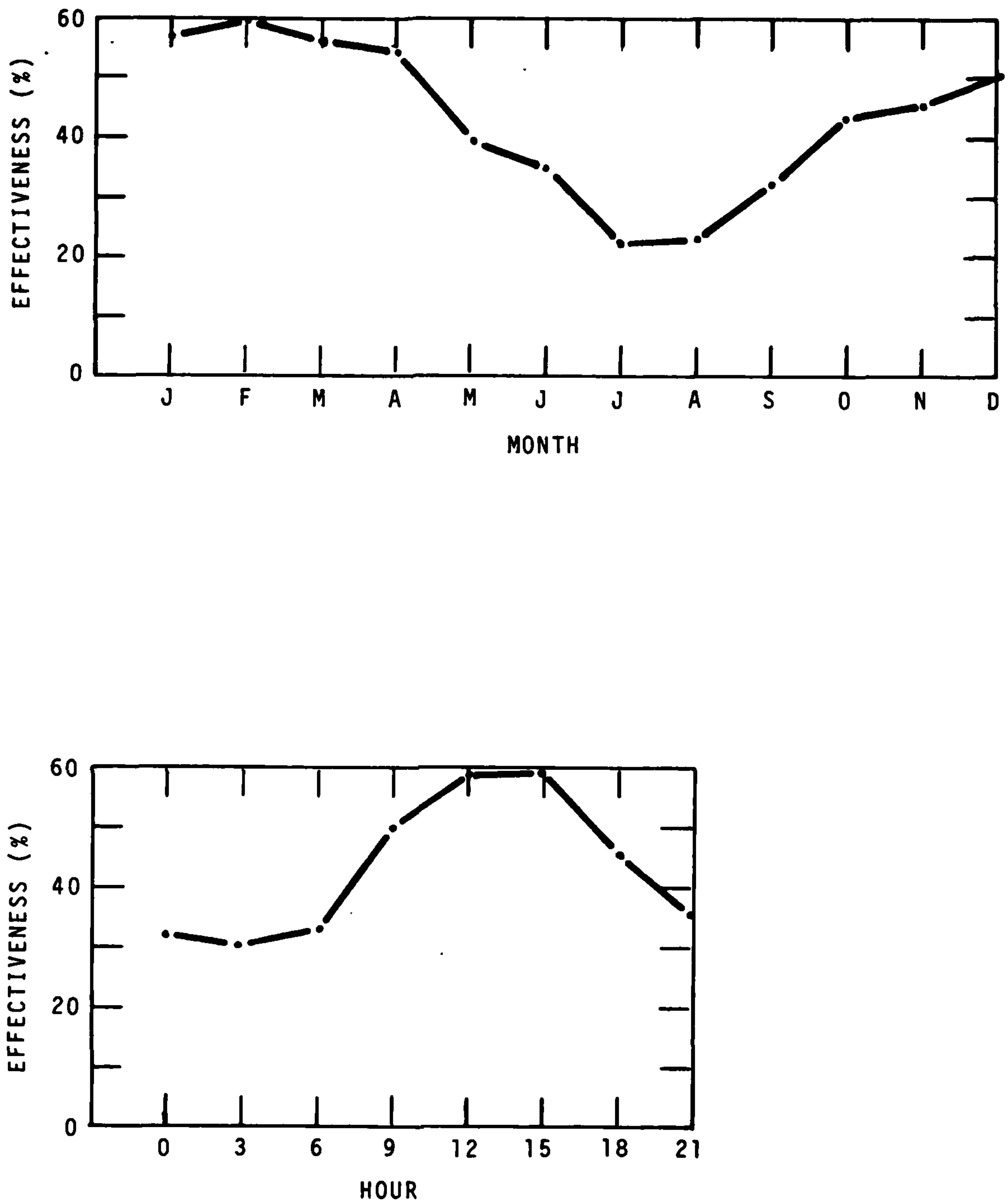


FIGURE 3. VAS EFFECTIVENESS FOR ORD RUNWAY 4/22

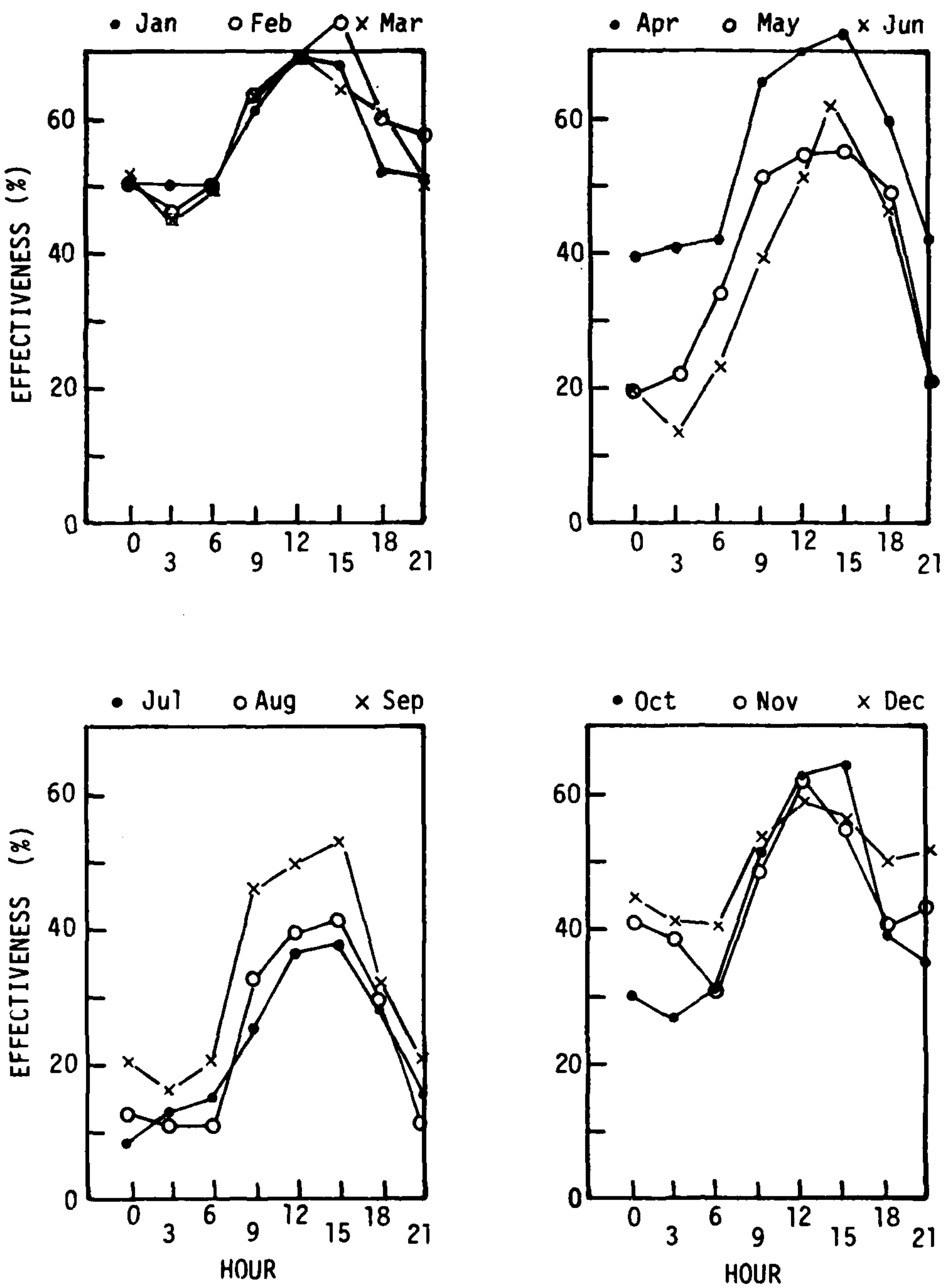


FIGURE 4. VAS EFFECTIVENESS FOR ORD RUNWAY 4/22 (CONCLUDED)

values. Averaging the 8 values for April gives the 53-percent effectiveness shown in Figure 3 (top graph); averaging the 12 values for midnight Local Time gives the 32-percent effectiveness value shown in Figure 3 (bottom graph).

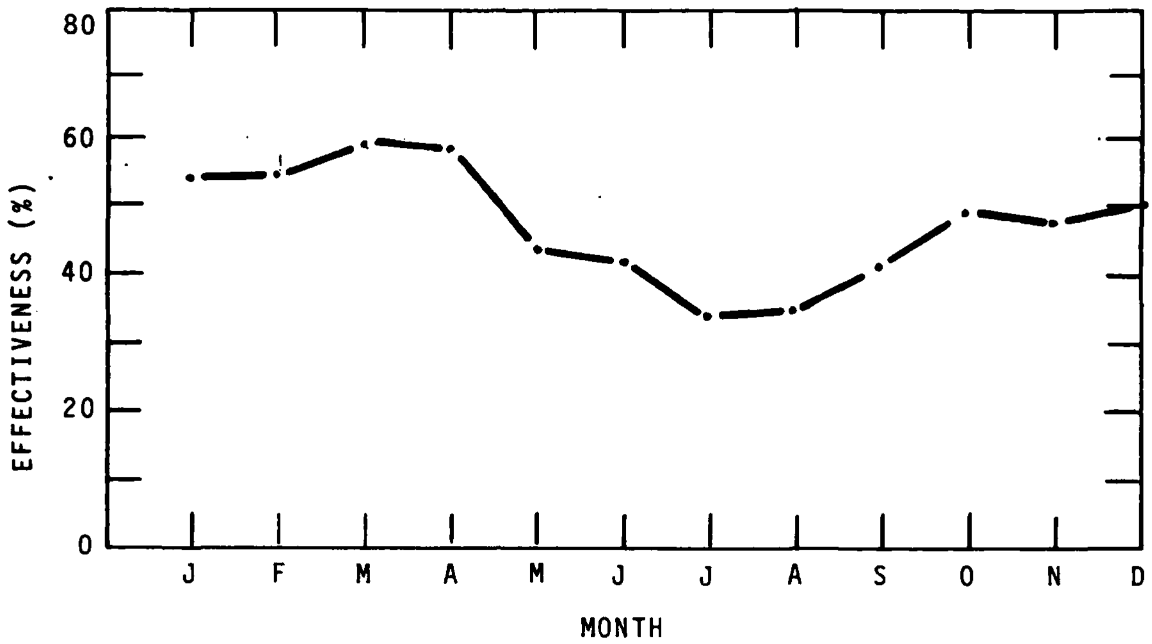
Figure 3 (top graph) shows the expected variation of effectiveness with the month of the year. The winter months at ORD are, in general, relatively windy leading to an anticipated maximum effectiveness in February. The summer months in contrast are relatively mild with the attendant lower winds and hence lower VAS effectiveness.

Figure 3 (bottom graph) shows that the VAS effectiveness peaks in the early afternoon and reaches a minimum in the early morning hours. The temporal dependence is sinusoidal in nature with a mean or d-c level of approximately 45-percent effectiveness.

Figure 4 shows these same trends. The effectiveness values vary from a low of 9 percent at midnight in July to a high of 75 percent at 1500 hours in February. The four graphs show that the VAS effectiveness curves correlate with the season.

Figures 5 to 8 contain the effectiveness data for runways 9/27 and 14/32. The trends are the same as for runway 4/22. Including all three runway pairs, the effectiveness values vary from a low of 9 percent at midnight in July (runway 4/22) to a high of 83 percent at 1500 hours in April (runway 14/32).

An important consideration is the degree of correlation of peaks in VAS effectiveness with the arrival demand. Figure 9 shows the VAS effectiveness curve (solid dots and line) and an arrival demand curve (open circles and broken line) for ORD as a function of Local Time. The effectiveness curve is an average for the three sets of parallel runways (4/22, 9/27 and 14/32). The number of scheduled arrivals was obtained from the Official Airline Guide (Ref. 9) for the first Tuesday in November 1977. Although the number of arrivals would be different if another day or season or year were used, the shape for the curve would remain about the same.



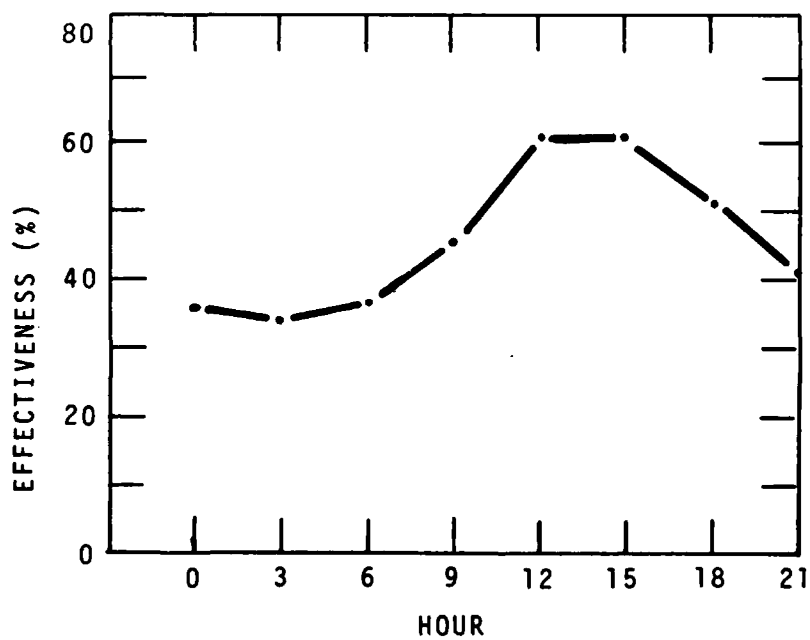


FIGURE 5. VAS EFFECTIVENESS FOR ORD RUNWAY 9/27

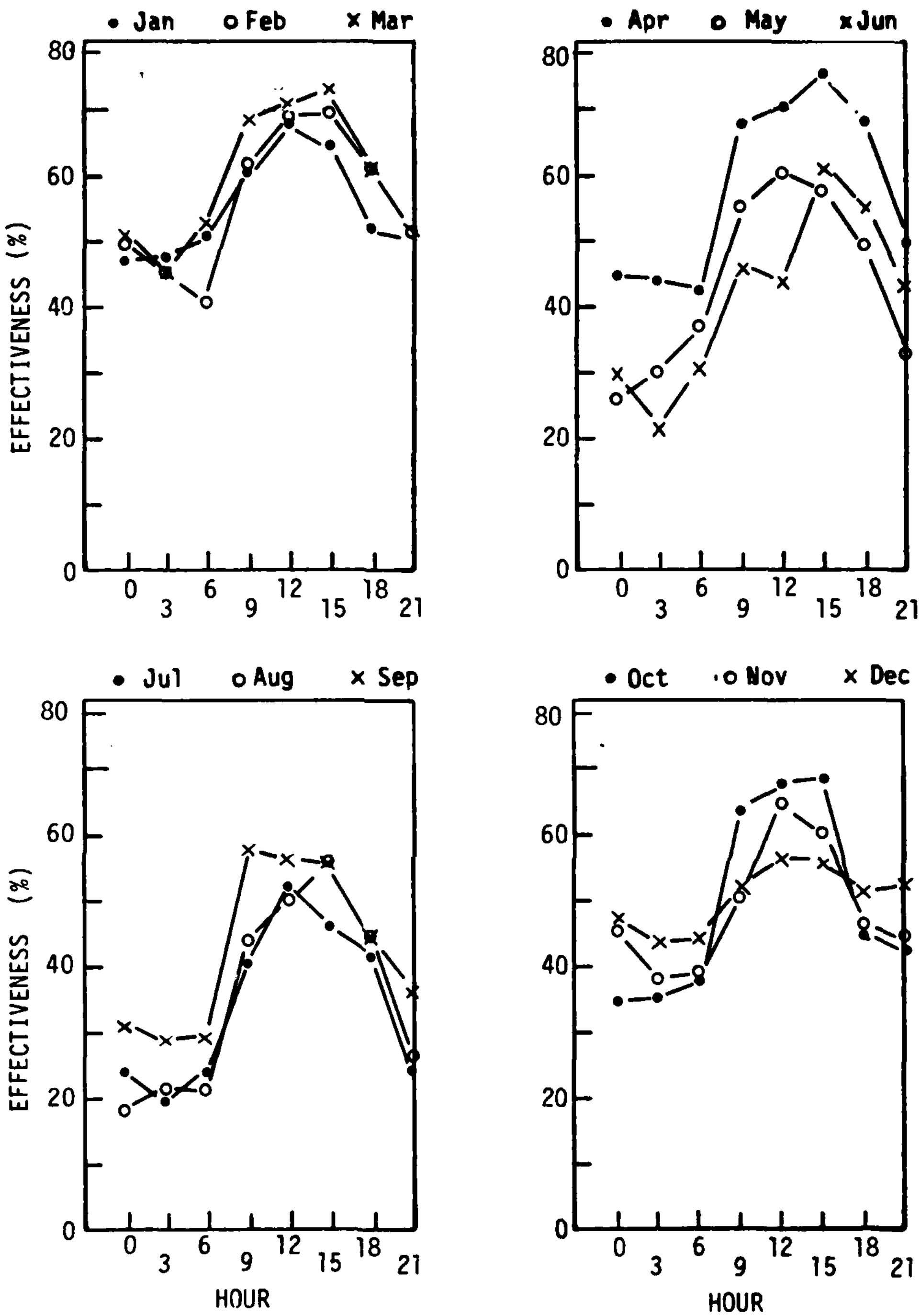
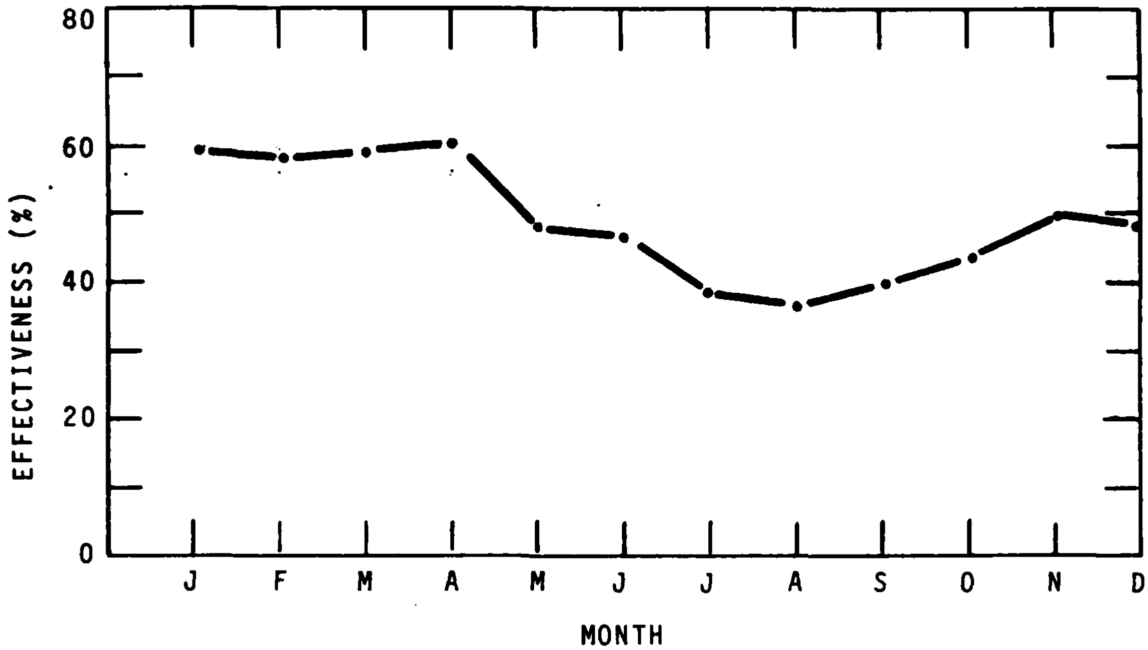


FIGURE 6. VAS EFFECTIVENESS FOR ORD RUNWAY 9/27 (CONCLUDED)



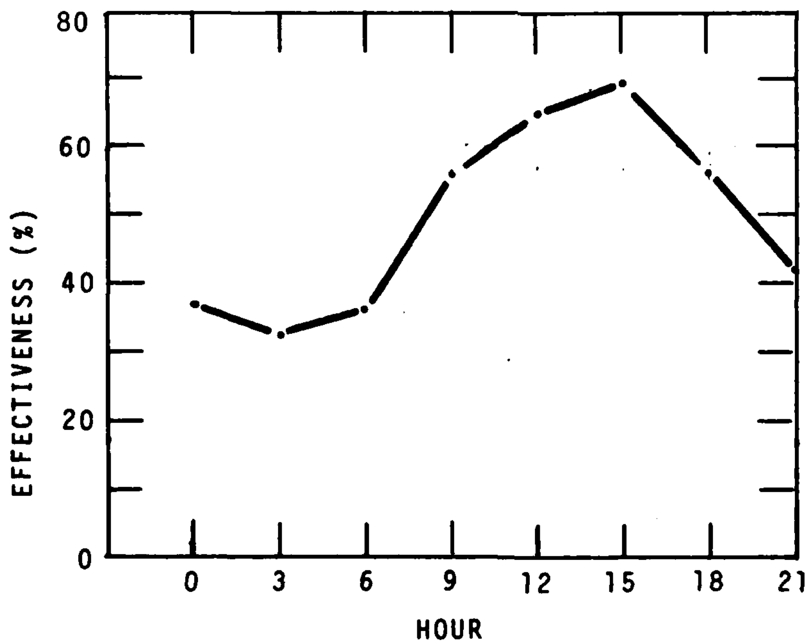


FIGURE 7. VAS EFFECTIVENESS FOR ORD RUNWAY 14/32

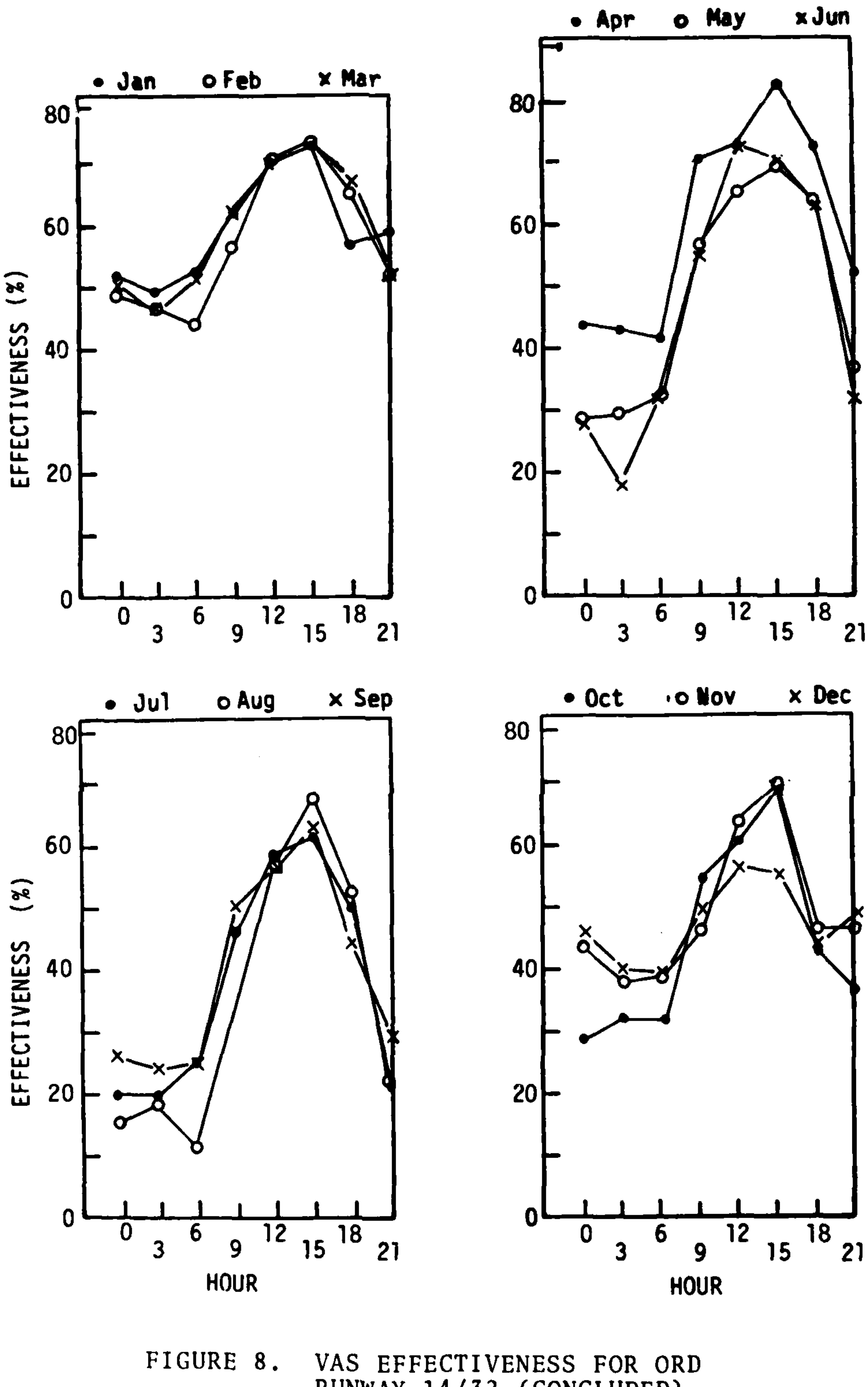


FIGURE 8. VAS EFFECTIVENESS FOR ORD RUNWAY 14/32 (CONCLUDED)

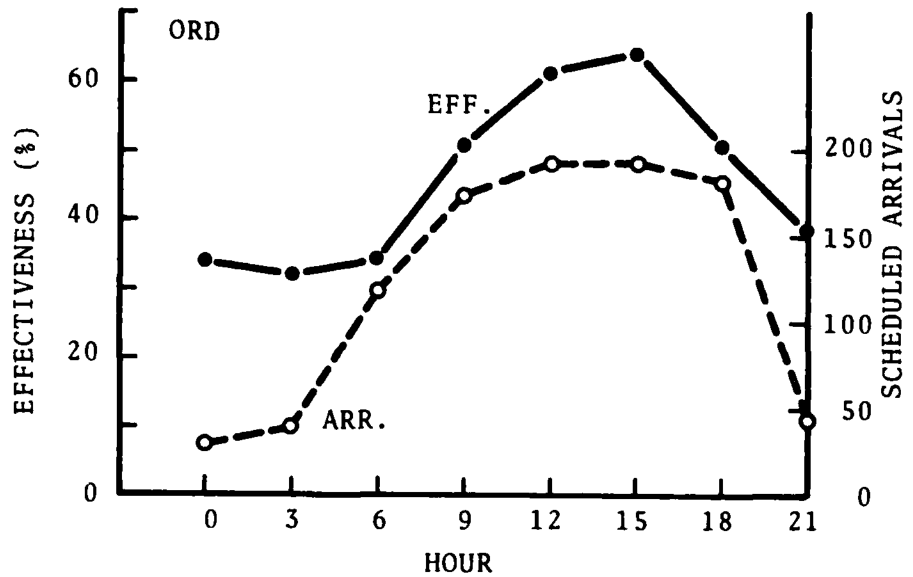


FIGURE 9. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR ORD

The important point of Figure 9 is that the VAS effectiveness peaks with the arrival demand at ORD. The relatively low effectiveness in the early morning hours is not significant since the airport has more than enough air/land space to accommodate the demand with little or no delay. Non-weather delays tend to build up in the early afternoon to early evening time period at ORD. The VAS effectiveness is seen to follow the arrival demand, and the higher percentages occur when the delays are most prevalent. Averaged over the whole day, the effectiveness at ORD is 48 percent; averaged over the afternoon hours (1200 to 1800), the effectiveness is 69 percent.

3.2 WILLIAM B. HARTSFIELD ATLANTA INTERNATIONAL AIRPORT

The William B. Hartsfield Atlanta International Airport (ATL) has one set of parallel runways, 9/27, and runway 8/26. Figures 10 to 13 show the effectiveness calculated for these runways. The effectiveness values range from a low of 2 percent at midnight in August (runway 8/26) to a high of 63 percent at 1500 hours in April (runway 8/26).

Figure 14 shows the VAS effectiveness and number of scheduled arrivals at ATL as a function of the hour. ATL has a double hump arrival demand curve, but the VAS effectiveness is greatest when the demand is greatest.

3.3 LOGAN INTERNATIONAL AIRPORT

Logan International Airport (BOS) in Boston has two sets of parallel runways (4/22 and 15/33) and runway 9/27. Figures 15 to 20 show the effectiveness values which range from a low of 18 percent at midnight in July (runway 4/22) to a high of 79 percent at 1500 hours in April (runway 4/22). During the winter months, the VAS effectiveness rarely drops below 60 percent.

As can be seen in Figure 21, the VAS-effectiveness maximum correlates with the maximum number of scheduled arrivals. BOS has a relatively high average effectiveness. The peak effectiveness occurs at 1500 hours when the arrival demand is greatest.

3.4 WASHINGTON NATIONAL AIRPORT

Washington National Airport (DCA) does not service Heavy jets, but there is a large proportion of Small aircraft mixed with Large aircraft. The VAS may help to minimize delays by permitting the Small aircraft to land 3 nautical miles behind the Large aircraft. DCA has one main ILS runway, 18/36, and two shorter non-ILS runways, 3/21 and 15/33. Figures 22 and 23 show the effectiveness for runway 18/36; the values range from a low of 5 percent at 0300 in July to a high of 50 percent at 1500 hours in February.

As can be seen in Figure 24, the VAS effectiveness and the number of scheduled arrivals have similar trends. The two curves track each other with the maximum values occurring in the early afternoon and the minimum values occurring in the early morning.

3.5 STAPLETON INTERNATIONAL AIRPORT

Stapleton International Airport (DEN) in Denver has one set of triple parallel runways, 17/35; one set of double parallel runways, 8/26; and one short runway, 7/25. Two of the runways in the triple set and one of the double set are ILS-equipped. Figures 25 through 28 show the calculated VAS effectiveness for these ILS runways; the values range from a low of 6 percent at 0600 in July (runway 17/35) to a high of 62 percent at 1800 hours in March (runway 17/35).

Figure 29 shows the VAS effectiveness and the number of scheduled arrivals as a function of the hour. Because of its location, traffic in the mid-morning to mid-afternoon time period may be greatest since the aircraft stopping at DEN are on their way to both coasts. The effectiveness curve peaks later (1800 hours), and DEN is the only instance where the two maximums do not occur at the same hour.

3.6 DALLAS-FORT WORTH REGIONAL AIRPORT

The Dallas-Fort Worth Regional Airport (DFW) has one set of parallel runways (17-35) in addition to 13L/31R. All are ILS-equipped. Figures 30 to 33 show the calculated effectiveness values for these runways; the values range from a low of 5 percent at midnight to 0300 in August (runway 17/35) to a high of 76 percent at noon in January, February, and March (runway 13/31).

Figure 34 shows that when the number of scheduled arrivals is greatest (0900 to 1800), the calculated VAS effectiveness is also greatest.

3.7 DETROIT METROPOLITAN WAYNE COUNTY AIRPORT

The Detroit Metropolitan Wayne County Airport (DTW) has two ILS-equipped runways, 3L/21R and 9/27. Runway 3C/21C is not ILS equipped. Figures 35 to 38 show the effectiveness values for runways 3/21 and 9/27; the values range from a low of 11 percent at midnight in August (runway 3/21) to a high of 83 percent at 1500 hours in April (runway 3/21).

The hourly variation of VAS effectiveness and number of scheduled arrivals are shown in Figure 39.

3.8 JOHN F. KENNEDY INTERNATIONAL AIRPORT

The John F. Kennedy International Airport (JFK) in Jamaica, New York, has two sets of parallel runways, 4/22 and 13/31, and a short runway for general aviation use, 14/32. Only the parallels are ILS-equipped. Figures 40 to 43 show the calculated VAS effectiveness for the two sets of parallel runways; the values range from a low of 19 percent at 0300 in August (runway 4/22) to a high of 88 percent at 1500 hours in April (runway 4/22).

Figure 44 shows the VAS effectiveness and the number of scheduled arrivals as a function of the hour. JFK exhibits a distinct arrival peak at 1500 hours; the average VAS effectiveness peaks at about 75 percent at 1500 hours.

3.9 LOS ANGELES INTERNATIONAL AIRPORT

Los Angeles International Airport (LAX) has two sets of parallel runways (6/24 and 7/25) and one short runway (8/26). The parallels are ILS-equipped. Figures 45 to 48 show the calculated effectiveness for these runways; the values range from a low of about 1 percent in the early morning hours (0300 to 0600) in the spring and summer to a high of 43 percent at noon in April (runway 6/24). The VAS effectiveness values for LAX are the lowest of the 20 airports considered.

Figure 49 shows the average VAS effectiveness and the number of scheduled arrivals at LAX as a function of the time of day. The arrival demand has a double-peak spectrum peaking at 0900 and 1800 hours. The calculated VAS effectiveness peaks at 1500 hours, and the effectiveness value is not great compared with values for other airports.

3.10 LAGUARDIA AIRPORT

LaGuardia Airport (LGA) in East Elmhurst, New York, has three runways: 4/22 and 13/31, which are ILS-equipped; and 14/32, which is not. LGA has an aircraft mix of Large and Small; A-300s may soon be routinely added to the Eastern Airlines operations. Figures 50 to 53 show the calculated VAS effectiveness for runways 4/22 and 13/31; the values range from a low of 19 percent at 0300 in August (runway 4/22) to a high of 83 percent at 1500 hours in April (runway 4/22).

The effectiveness and the number of scheduled arrivals exhibit a similar temporal behavior as shown in Figure 54.

3.11 MIAMI INTERNATIONAL AIRPORT

Miami International Airport (MIA) has one set of east/west parallel runways, 9/27, and runway 12/30. The parallel runways are ILS-equipped. Figures 55 and 56 show the effectiveness values for runways 9/27; the values range from a low of 2 percent at 0300 in September to a high of 75 percent at noon in March and again at 1500 hours in April.

As shown in Figure 57, the plots of the hourly behavior of both the VAS effectiveness and the number of scheduled arrivals are very much alike.

3.12 MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT

The Minneapolis-St. Paul International Airport (MSP) has one set of parallel runways, 11/29, and runway 4/22. All the runways are ILS-equipped. Figures 58 to 61 show the VAS effectiveness for these runways; the values range from a low of 18 percent at 0300 in July (runway 4/22) to a high of 76 percent at 1500 hours in March (runway 4/22).

Figure 62 shows the averaged VAS effectiveness and the number of scheduled arrivals as a function of the hour. Although the arrival demand curve is a double hump, the peaks of the two curves occur at 1500 hours.

3.13 SEATTLE-TACOMA INTERNATIONAL AIRPORT

Seattle-Tacoma International Airport (SEA) has one set of ILS-equipped parallel runways, 16/34, and one short runway, 17/35, which does not have an ILS. Figures 63 and 64 show the calculated VAS effectiveness for runways 16/34; the values range from a low of 4 percent at 0600 hours in August to a high of 49 percent at noon in January.

Figure 65 shows the hourly behavior of both the averaged VAS effectiveness and the number of scheduled arrivals. Their curves exhibit a broad peak, and track each other.

3.14 SAN FRANCISCO INTERNATIONAL AIRPORT

San Francisco International Airport (SFO) has two sets of parallel runways, 1/19 and 10/28. Three of the runways are ILS-equipped. Figures 66 to 69 show the calculated VAS effectiveness values for runways 1/19 and 10/28; the values range from a low of 5 percent at 0300-0600 in September (runway 10/28) to a high of 98 percent at 1500 hours in August (runway 1/15). The effectiveness values for SFO in the mid-afternoon are the highest of the 20 airports considered.

Figure 70 shows the averaged VAS effectiveness and the number of scheduled arrivals as a function of hour. The arrival demand is relatively constant during the daylight hours with the VAS effectiveness maximizing at 1500 hours.

3.15 TAMPA INTERNATIONAL AIRPORT

Tampa International Airport (TPA) has one set of ILS-equipped parallel runways, 18/36, and one non-ILS-equipped runway, 9/27. Figures 71 and 72 show the calculated VAS effectiveness for runway 18/36; the values range from a low of 4 percent at 0300 in September to a high of 79 percent at 1500 hours in May.

Figure 73 shows the hourly behavior of both the VAS effectiveness and the number of scheduled arrivals. The arrival demand peaks at 1200 hours and the effectiveness peaks at 1500 hours, and the effectiveness is greatest when the demand is greatest.

3.16 CLEVELAND-HOPKINS INTERNATIONAL AIRPORT

Cleveland-Hopkins International Airport (CLE) has three sets of parallel runways: 5/23, 10/28, and 18/36. However, 5R/23L and 10L/28R both have ILS. Figures 72 to 77 show the effectiveness values; the values range from a low of 8 percent at 0300 hours in August (runway 5/23) to a high of 81 percent at 1500 hours in April (runway 10/28).

3.17 NEWARK INTERNATIONAL AIRPORT

Newark International Airport (EWR) has one set of ILS-equipped parallel runways, 4/22, and one non-ILS-equipped runway, 11/29. Figures 78 and 79 show the calculated VAS effectiveness values for runways 4/22. The values range from a low of 10 percent at 0300 hours in July to a high of 76 percent at 1500 hours in April.

3.18 PHILADELPHIA INTERNATIONAL AIRPORT

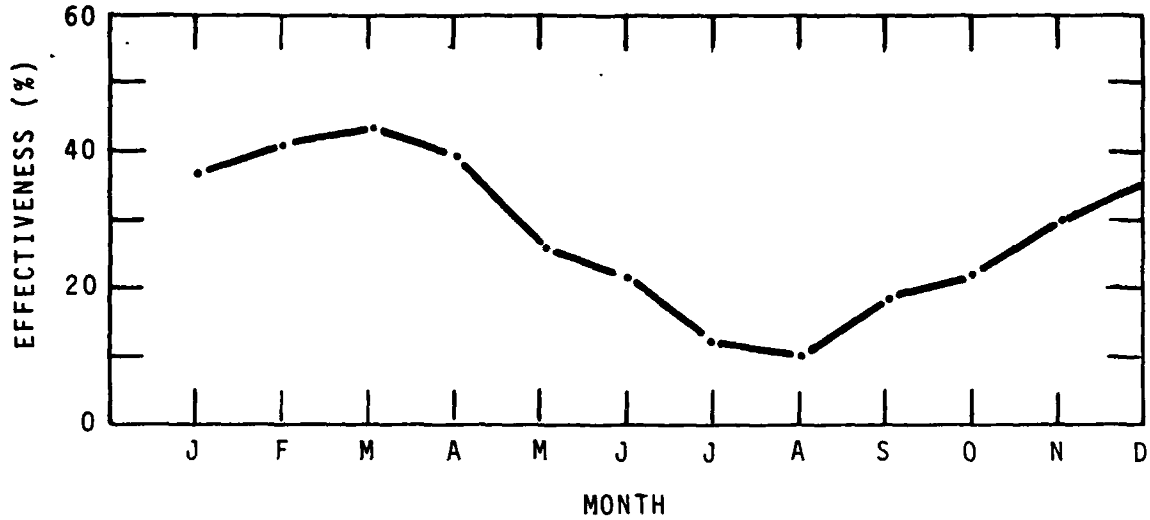
Philadelphia International Airport (PHL) has one set of ILS-equipped parallel runways, 9/27, and one non-ILS-equipped runway, 17/35. Figures 80 and 81 show the calculated VAS effectiveness values for runways 9/27; the values range from a low of 18 percent at midnight in August to a high of 71 percent at 1500 hours in April.

3.19 GREATER PITTSBURGH INTERNATIONAL AIRPORT

Greater Pittsburgh International Airport (PIT) has one set of ILS-equipped parallel runways, 10/28, one ILS-equipped runway, 14/32, and one runway without ILS equipment, 5/23. Figures 82 to 85 show the VAS effectiveness values for runways 10/28 and 14/32; the values range from a low of 5 percent at 0300 hours in August (runway 10/28) to a high of 70 percent at 1500 hours in April (runway 10/28).

3.20 LAMBERT-ST. LOUIS INTERNATIONAL AIRPORT

Lambert-St. Louis International Airport (STL) has one set of parallel runways, 12/30, one of which is ILS-equipped; runway 6/24 which is ILS-equipped, and runway 17/35 which is not ILS-equipped. Figures 86 to 89 show the calculated VAS effectiveness values for runways 6/24 and 12/30; the values range from a low of 10 percent at 0600 hours in August (runway 12/30) to a high of 76 percent at 1500 hours in March (runway 6/24).



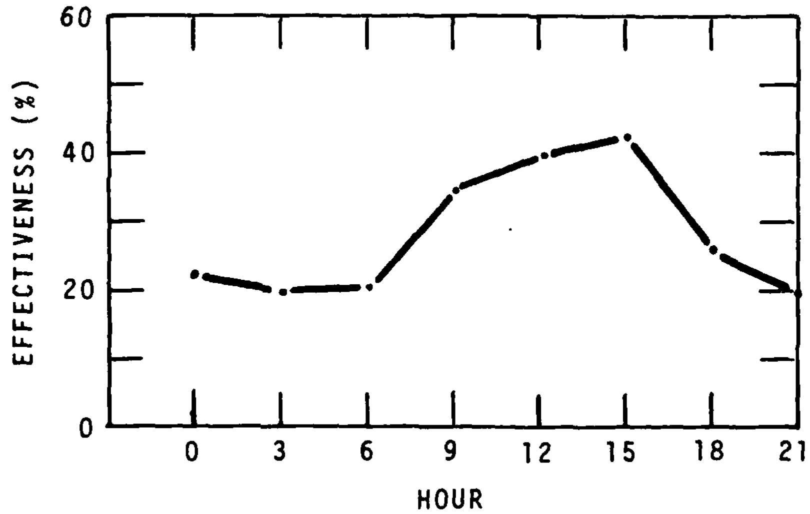


FIGURE 10. VAS EFFECTIVENESS FOR ATL RUNWAY 9/27

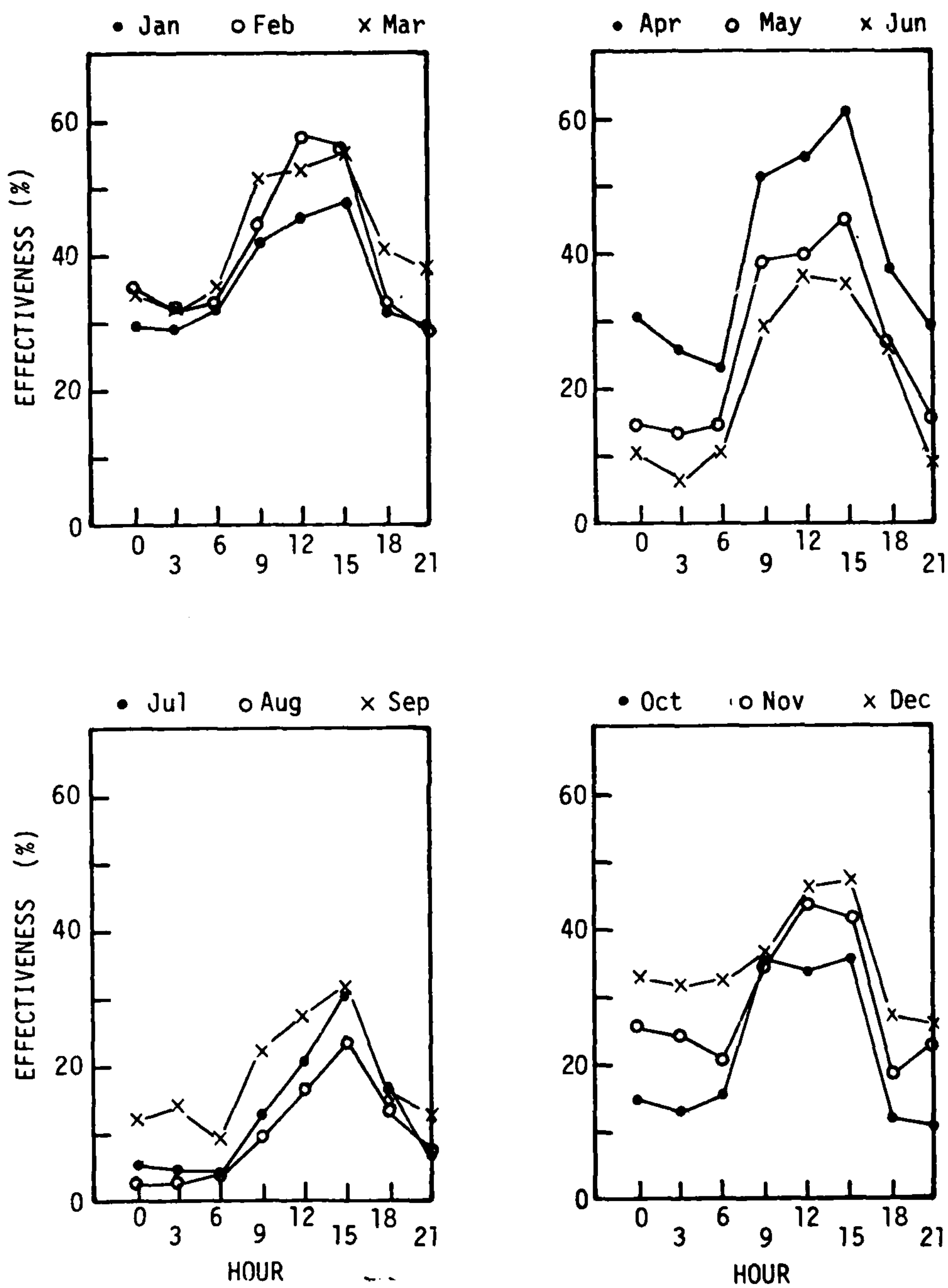
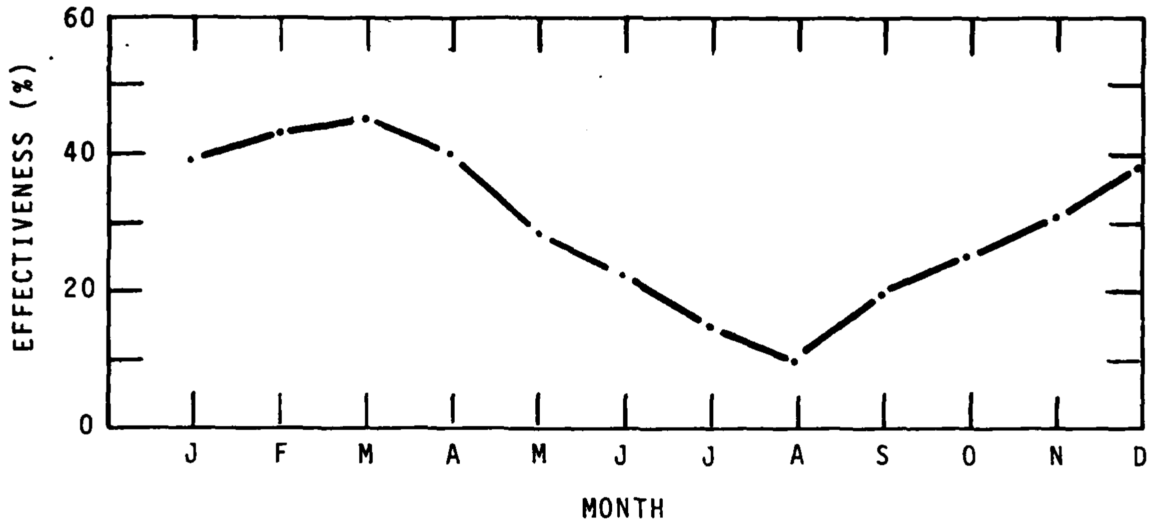


FIGURE 11. VAS EFFECTIVENESS FOR ATL RUNWAY 9/27 (CONCLUDED)



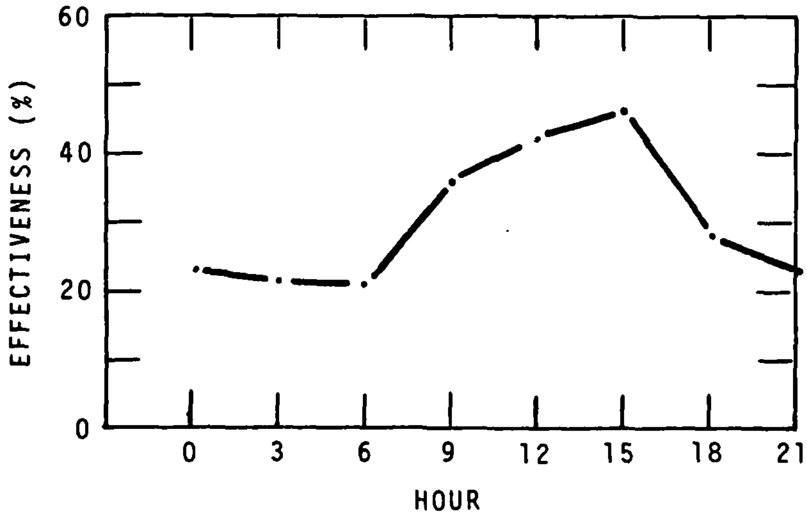


FIGURE 12. VAS EFFECTIVENESS FOR ATL RUNWAY 8/26

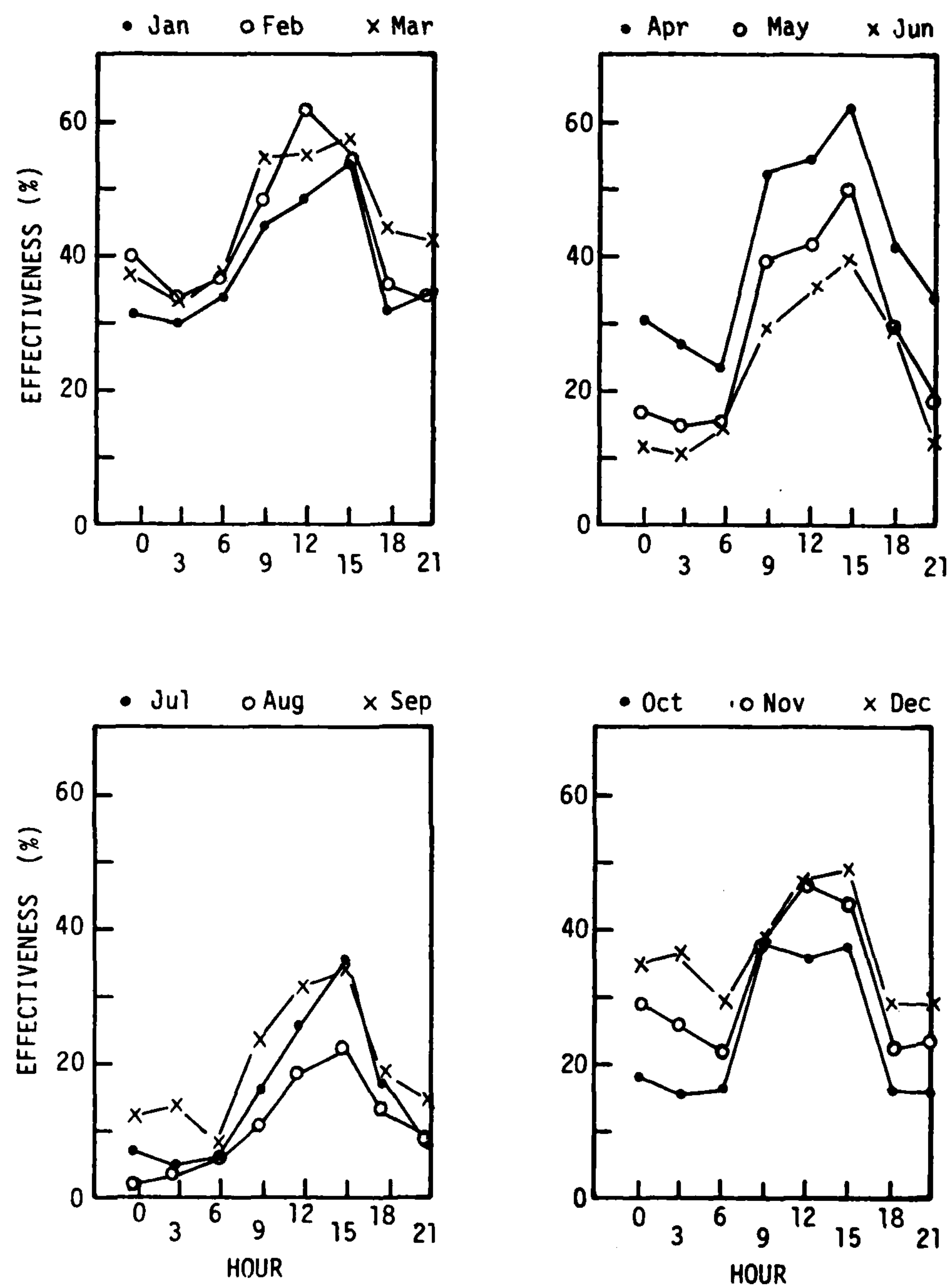


FIGURE 13. VAS EFFECTIVENESS FOR ATL RUNWAY 8/26 (CONCLUDED)

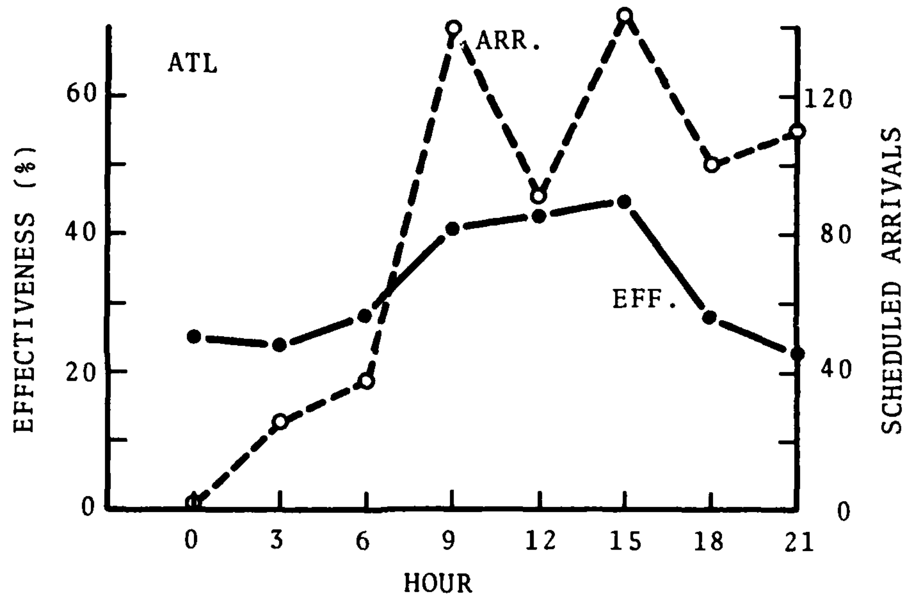
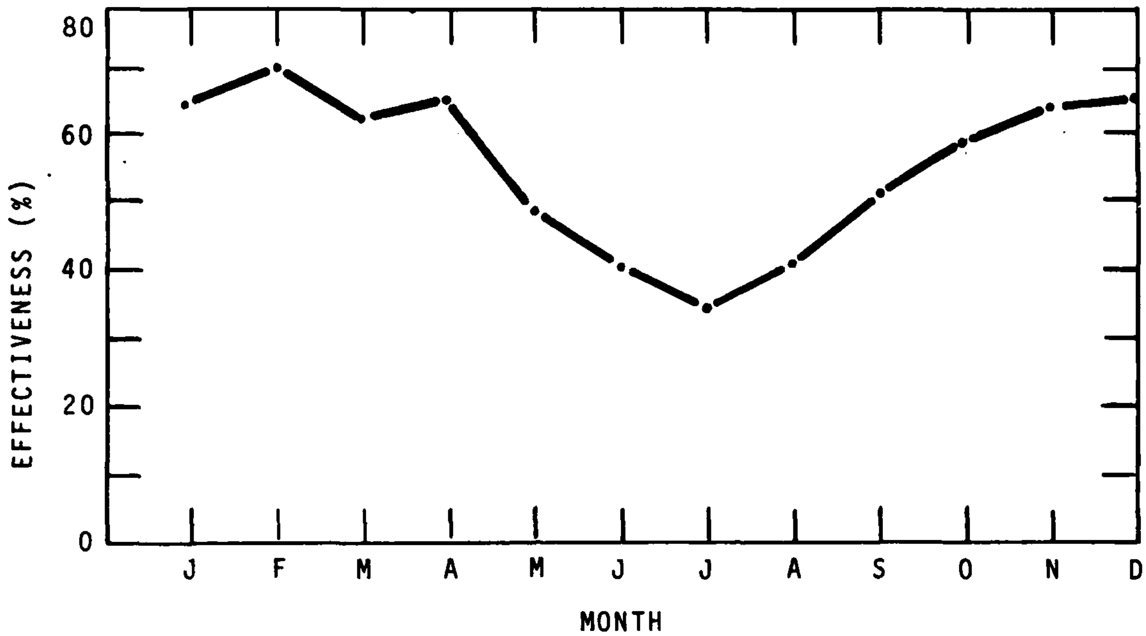


FIGURE 14. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR ATL



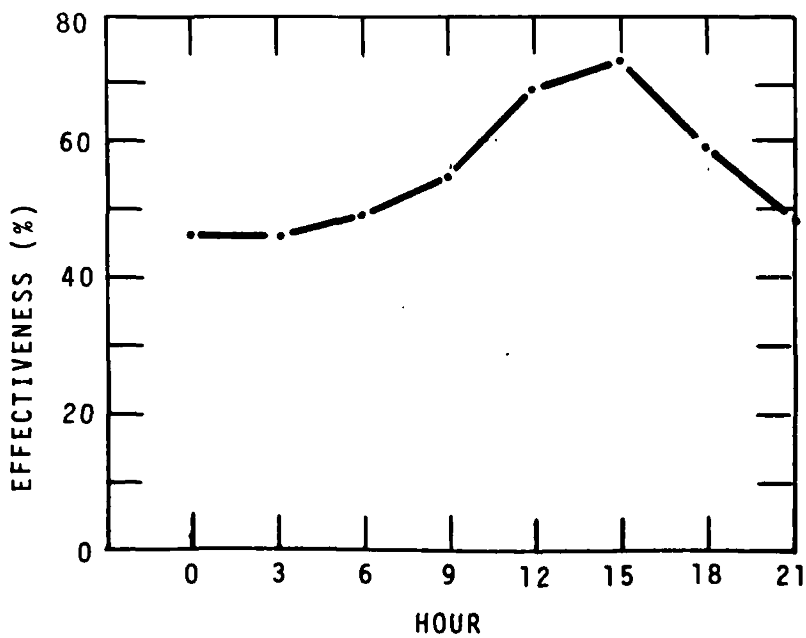


FIGURE 15. VAS EFFECTIVENESS FOR BOS RUNWAY 4/22

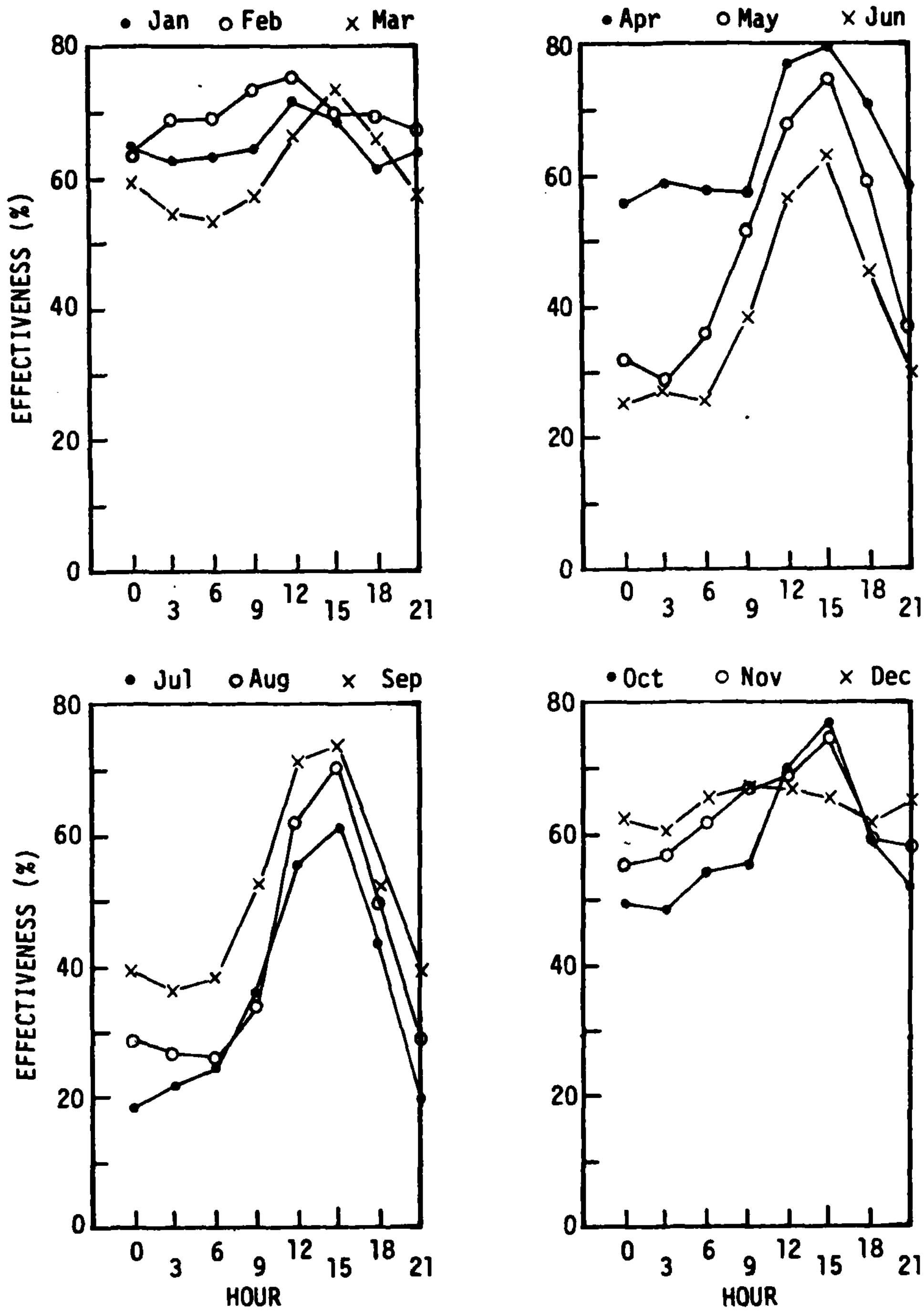
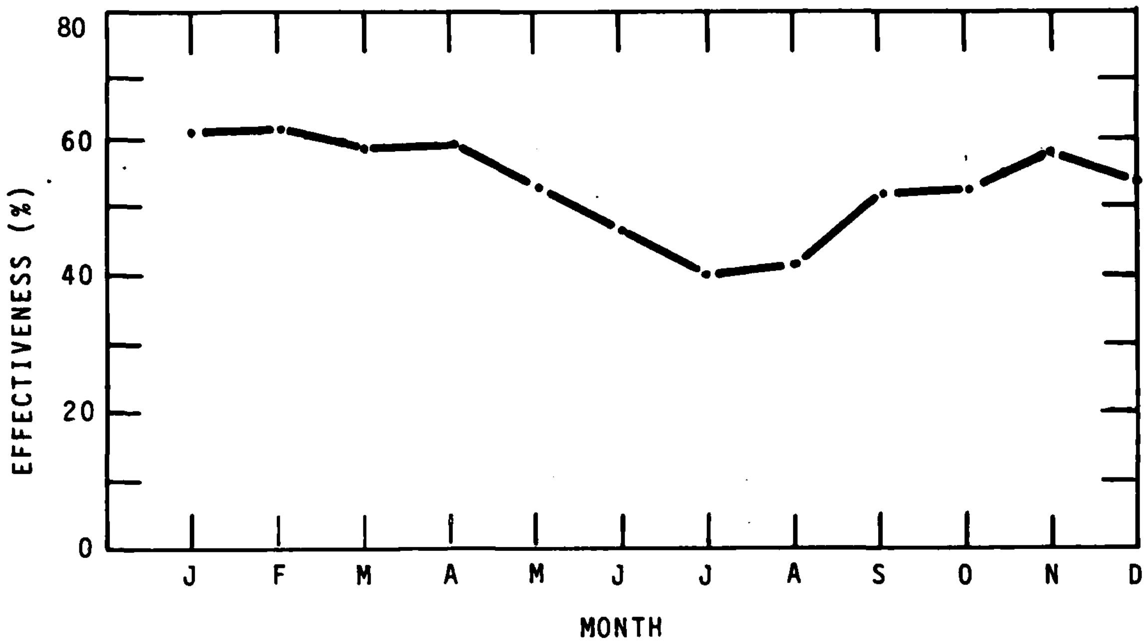


FIGURE 16. VAS EFFECTIVENESS FOR BOS RUNWAY 4/22 (CONCLUDED)



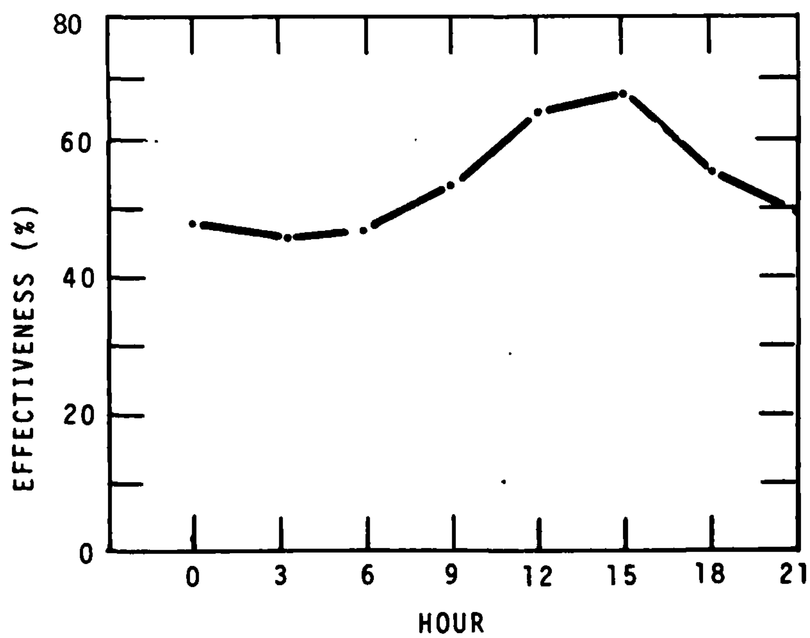


FIGURE 17. VAS EFFECTIVENESS FOR BOS RUNWAY 15/33

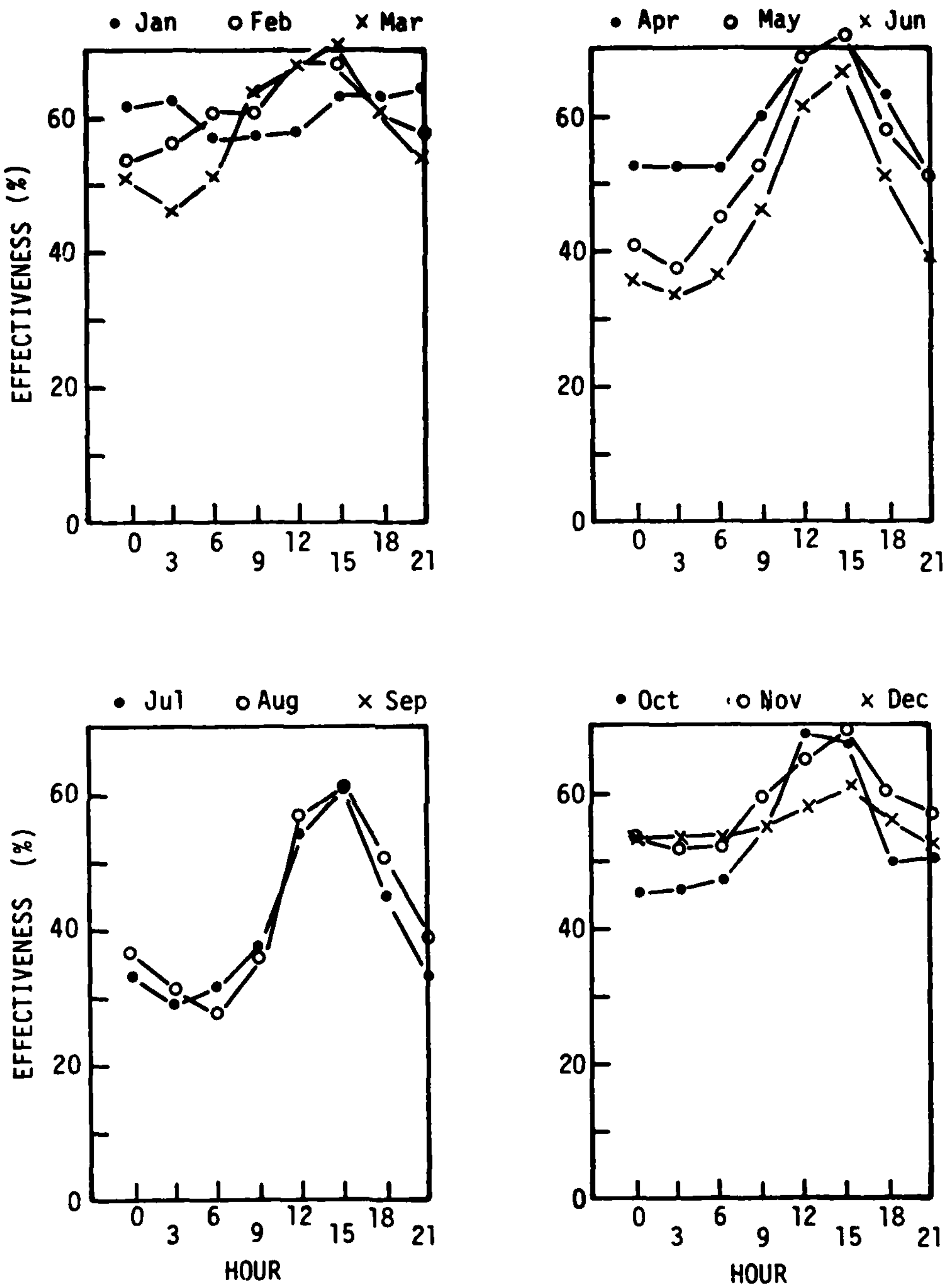
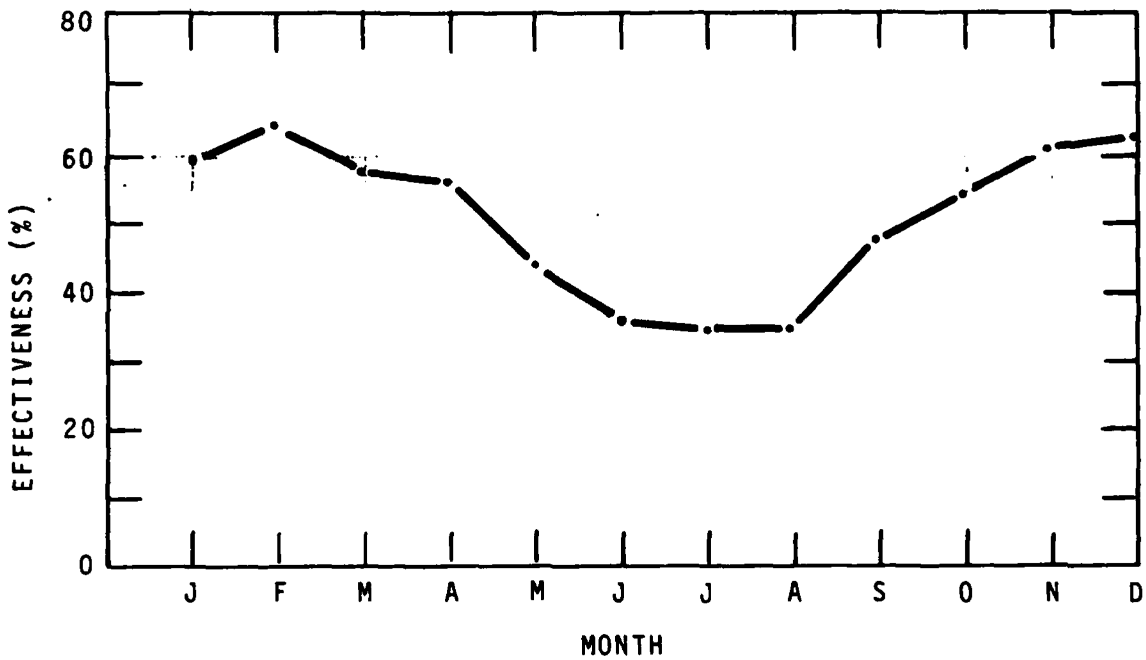


FIGURE 18. VAS EFFECTIVENESS FOR BOS RUNWAY 15/33 (CONCLUDED)



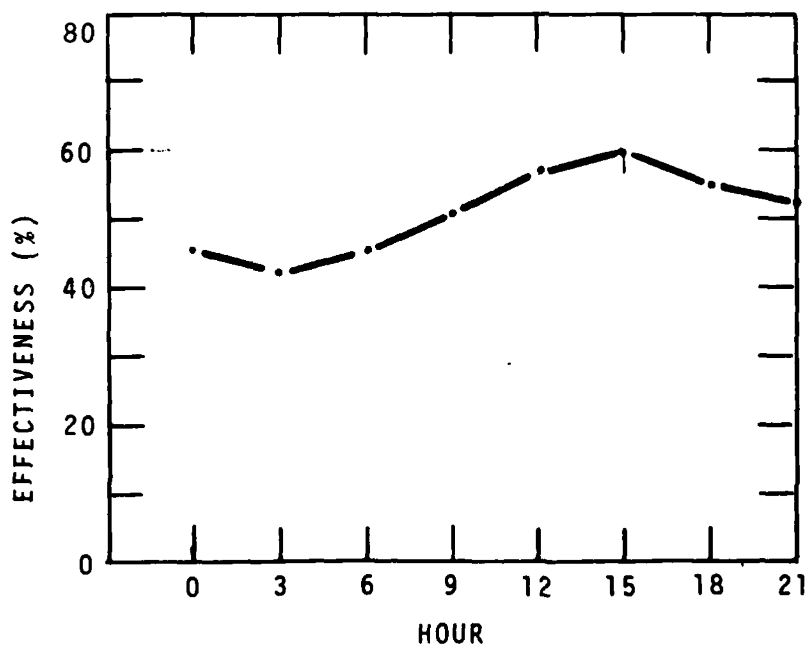


FIGURE 19. VAS EFFECTIVENESS FOR BOS RUNWAY 9/27

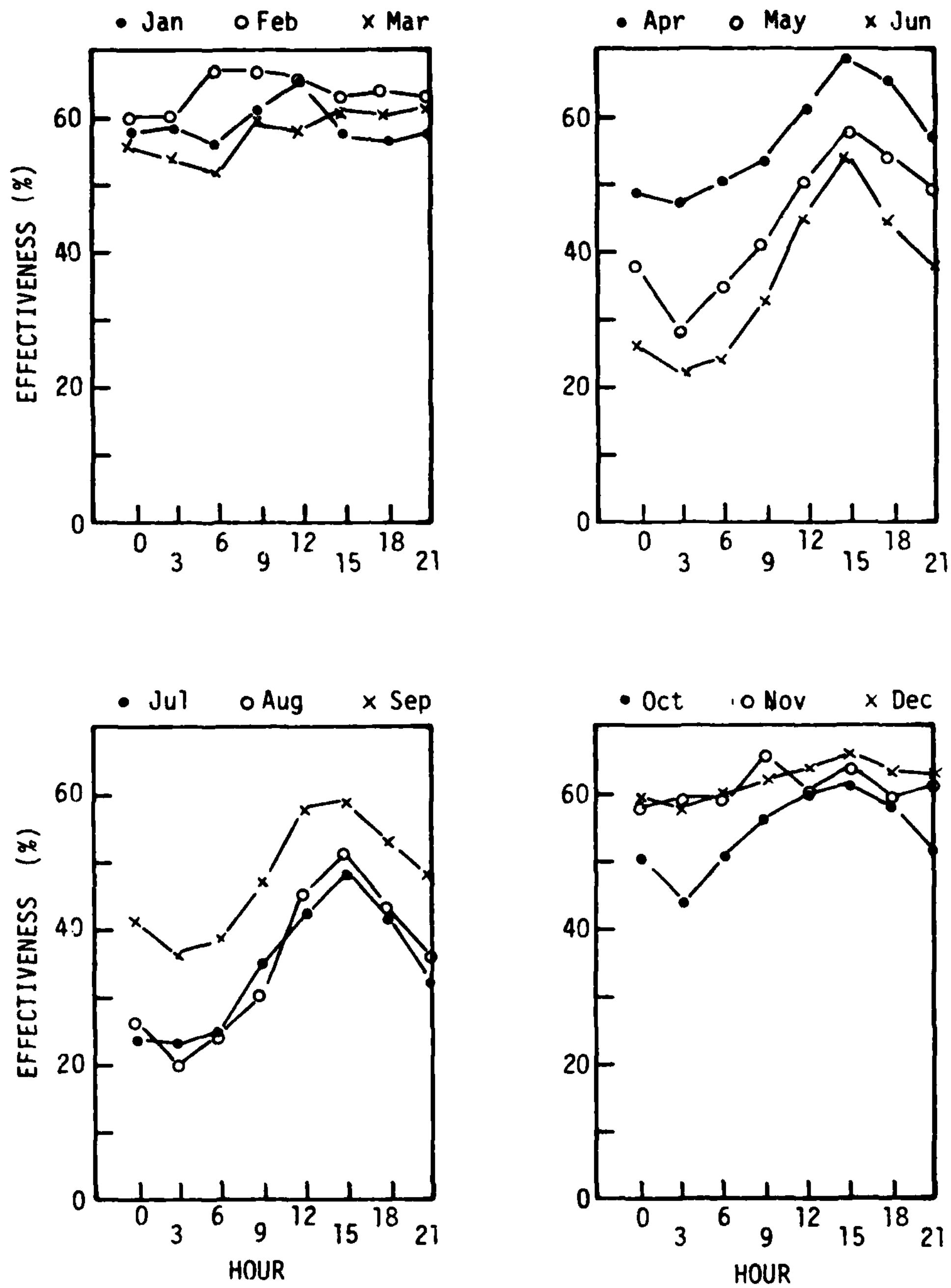


FIGURE 20. VAS EFFECTIVENESS FOR BOS RUNWAY 9/27 (CONCLUDED)

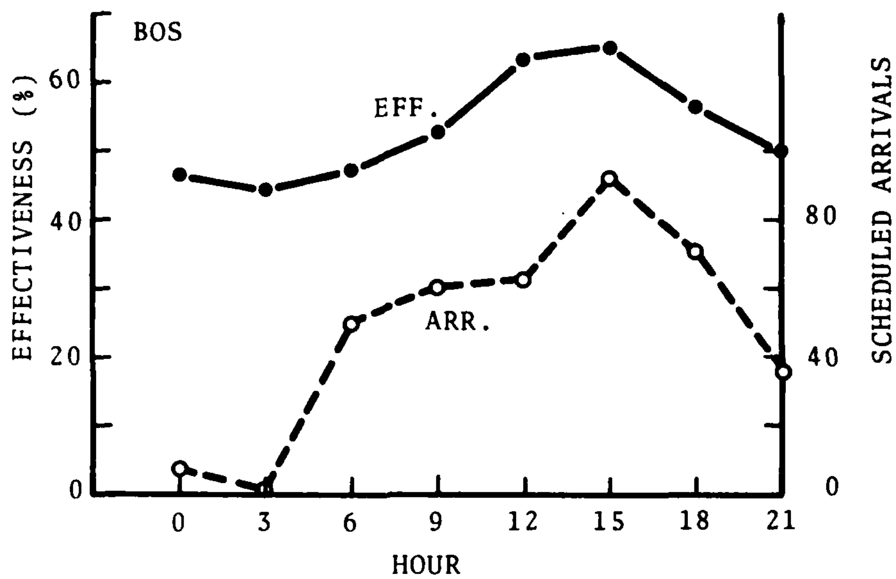
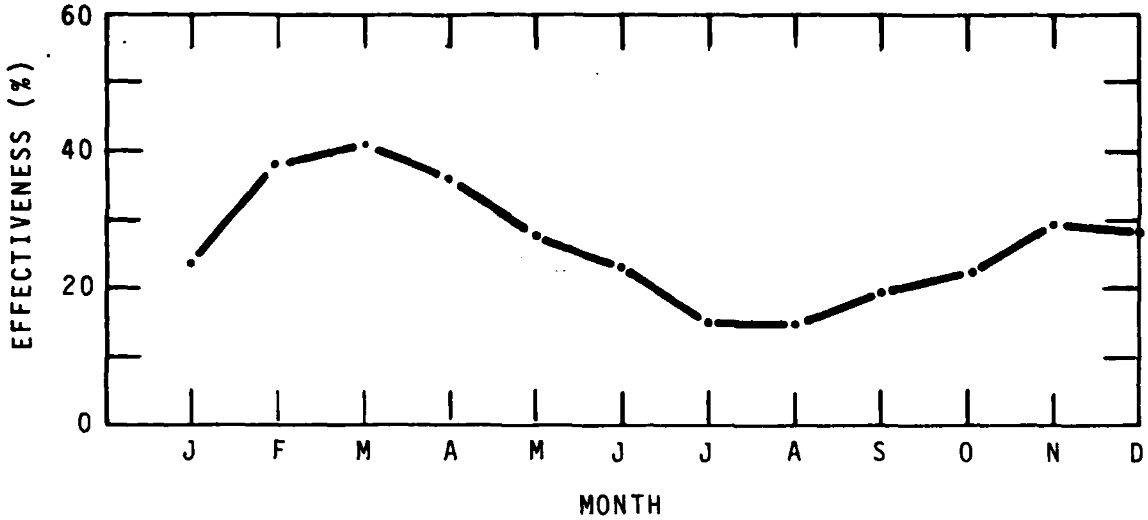


FIGURE 21. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR BOS



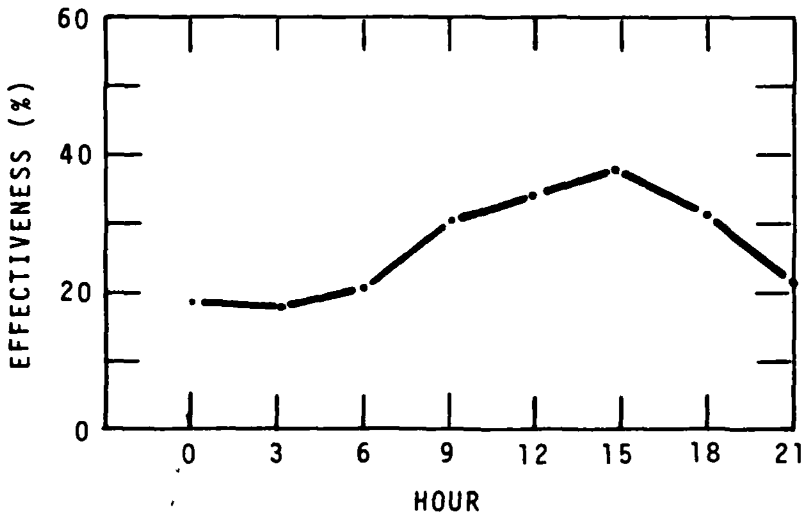


FIGURE 22. VAS EFFECTIVENESS FOR DCA RUNWAY 18/36

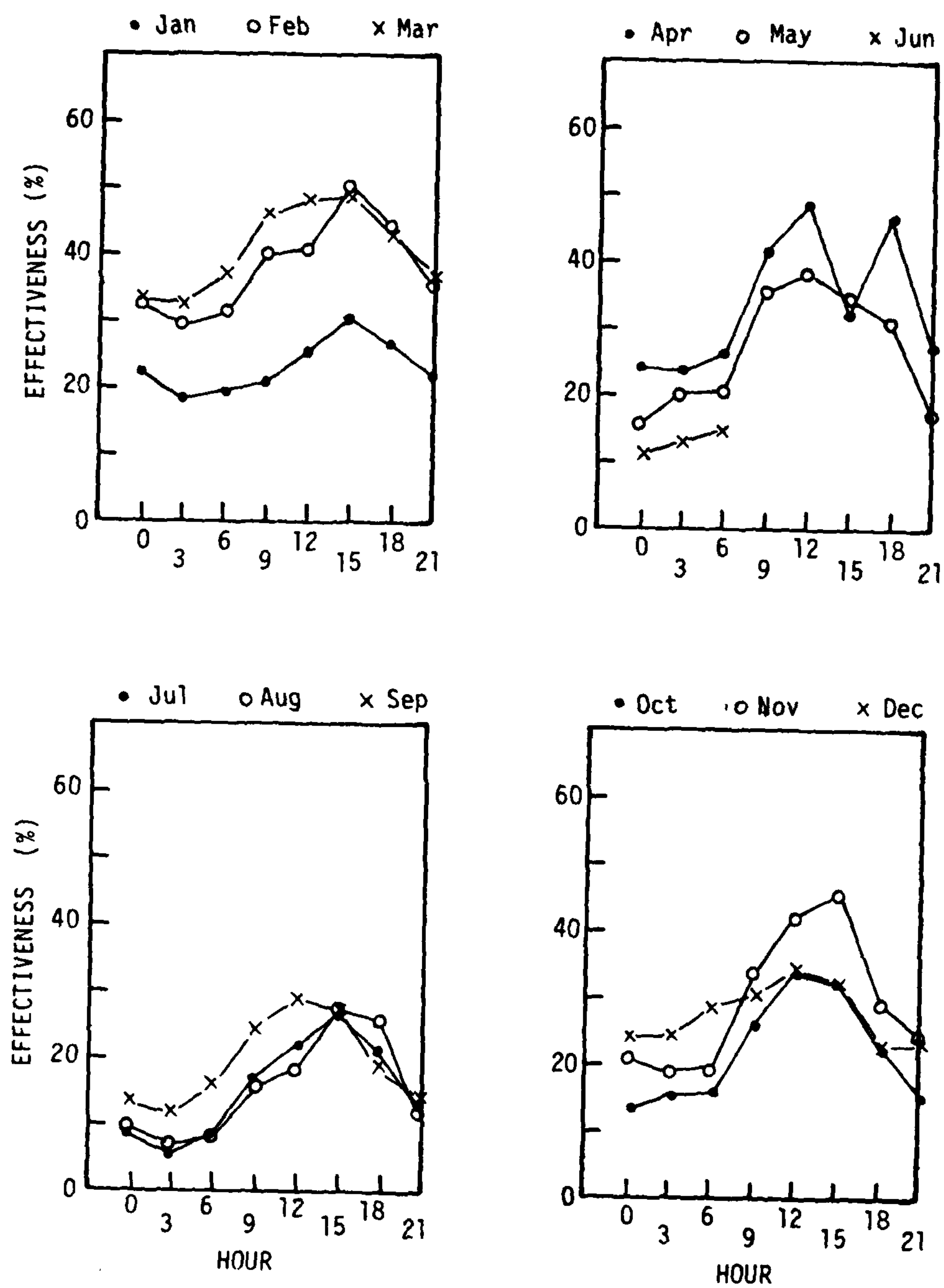


FIGURE 23. VAS EFFECTIVENESS FOR DCA RUNWAY 18/36 (CONCLUDED)

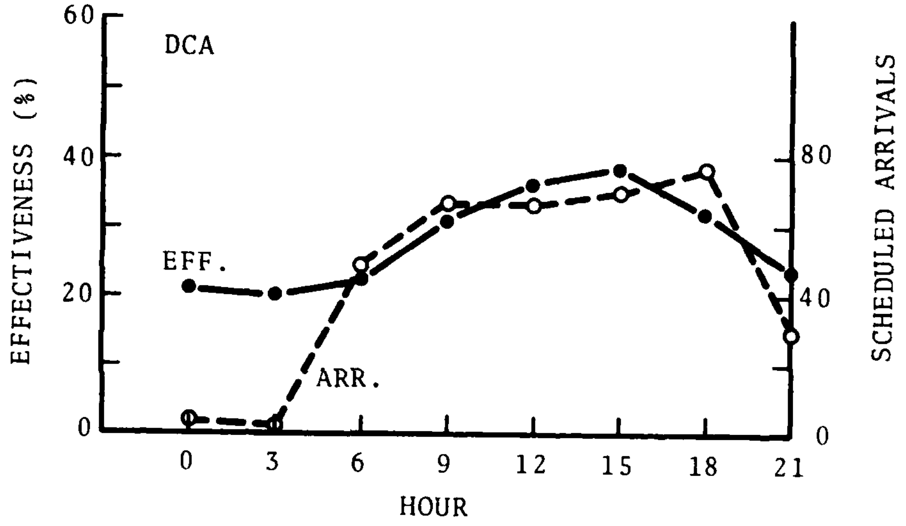
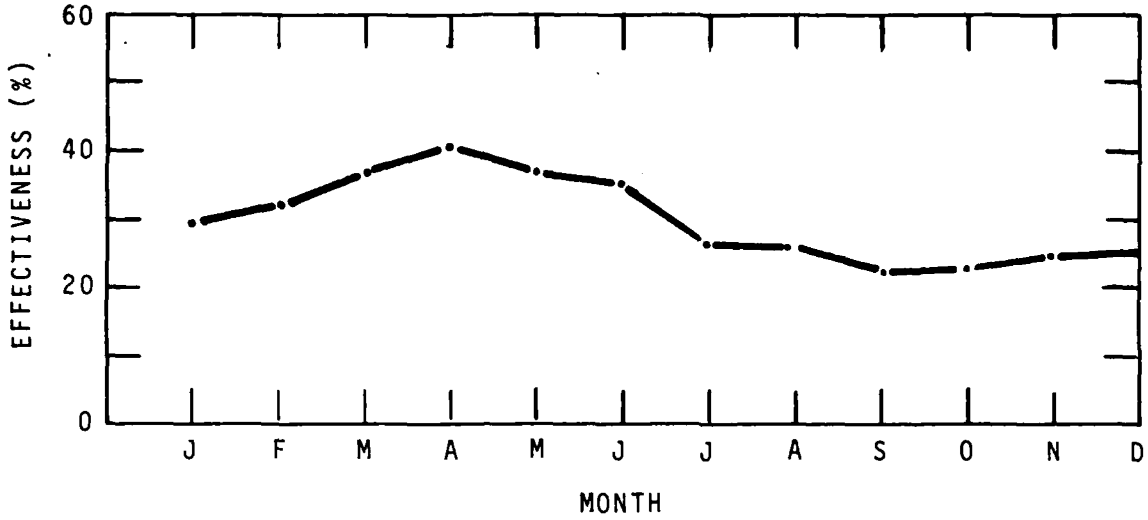


FIGURE 24. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR DCA



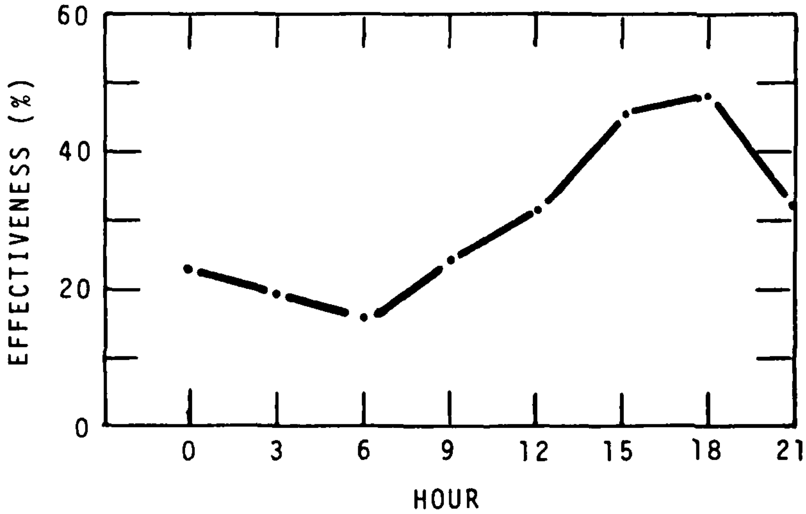


FIGURE 25. VAS EFFECTIVENESS FOR DEN RUNWAY 17/35

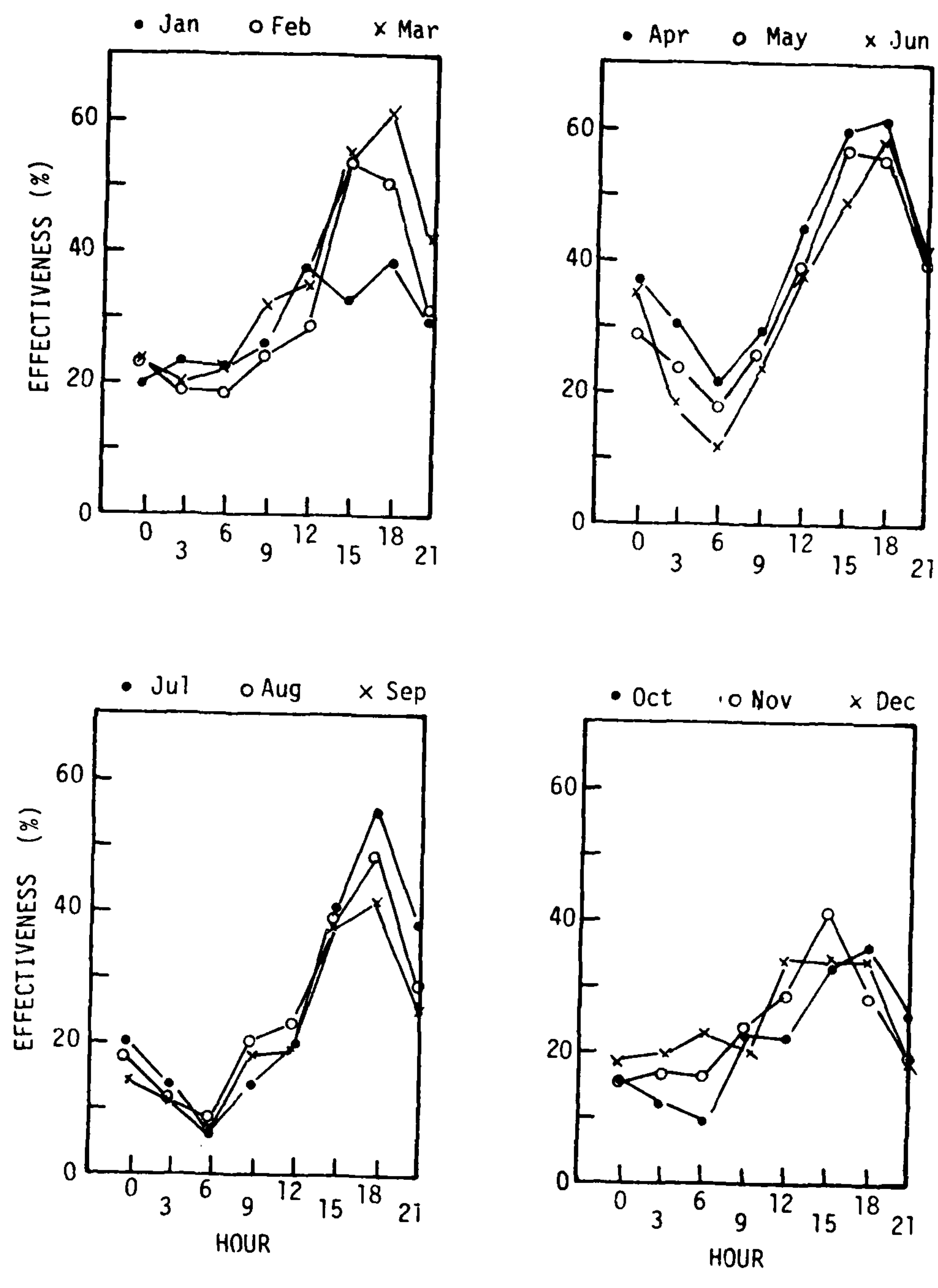
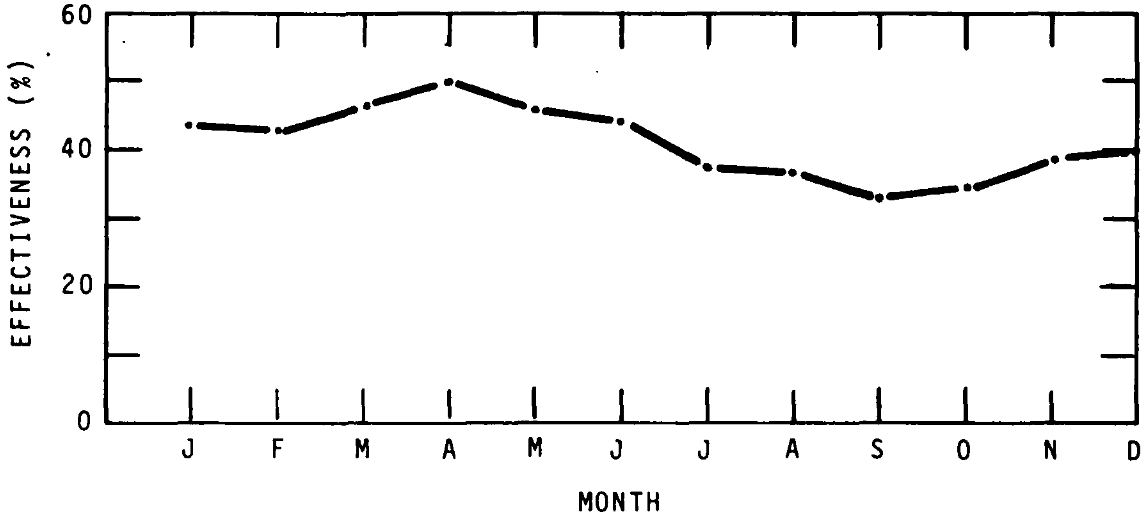


FIGURE 26. VAS EFFECTIVENESS FOR DEN RUNWAY 17/35 (CONCLUDED)



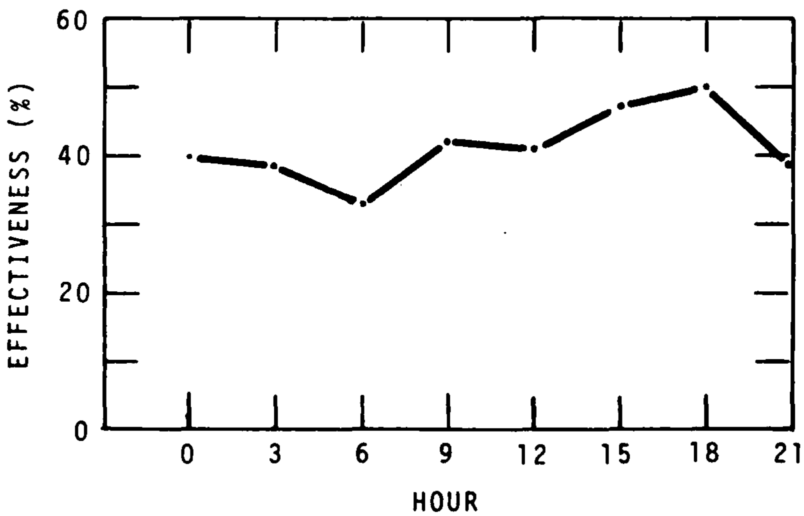


FIGURE 27. VAS EFFECTIVENESS FOR DEN RUNWAY 8/26

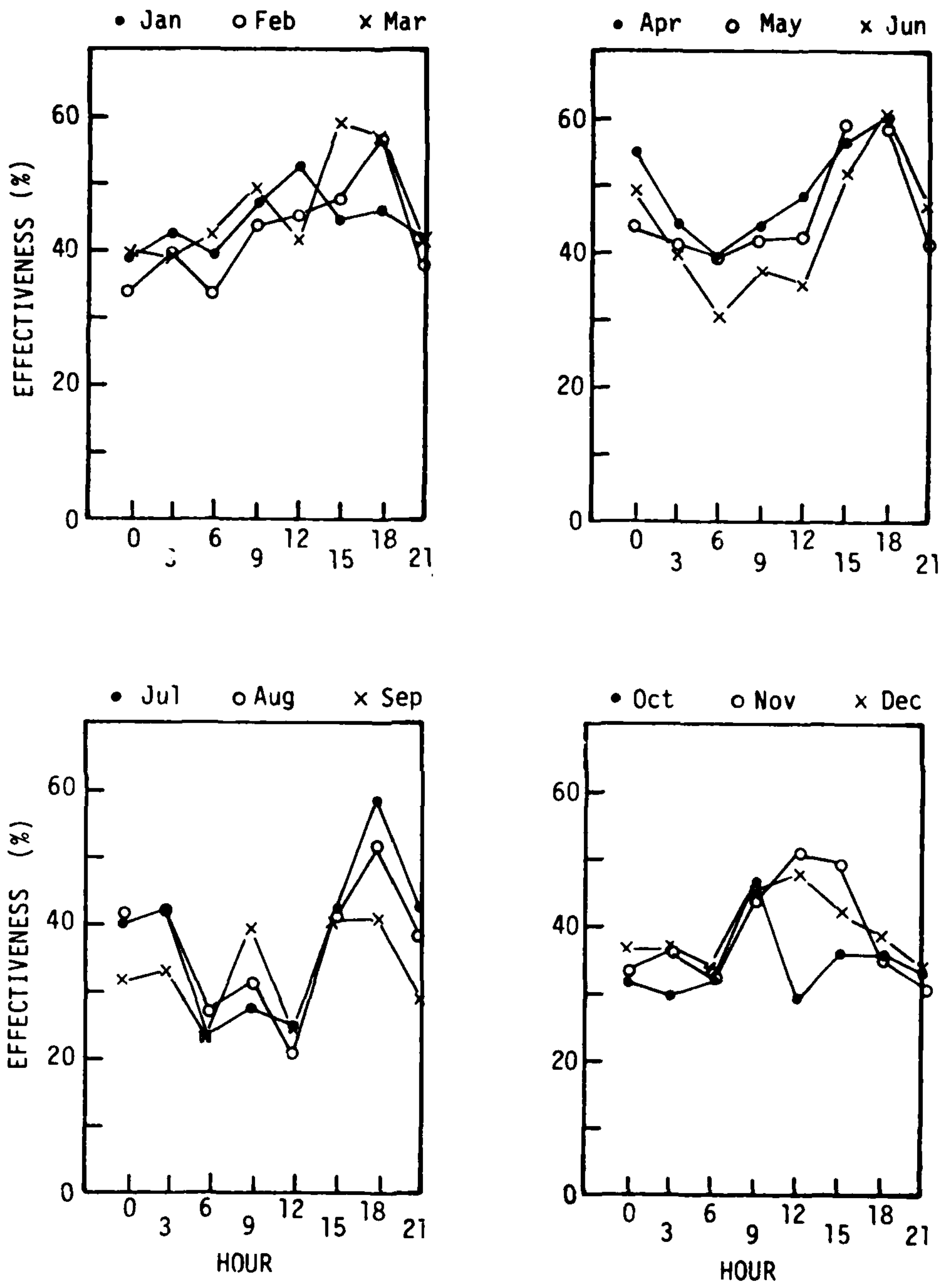


FIGURE 28. VAS EFFECTIVENESS FOR DEN RUNWAY 8/26 (CONCLUDED)

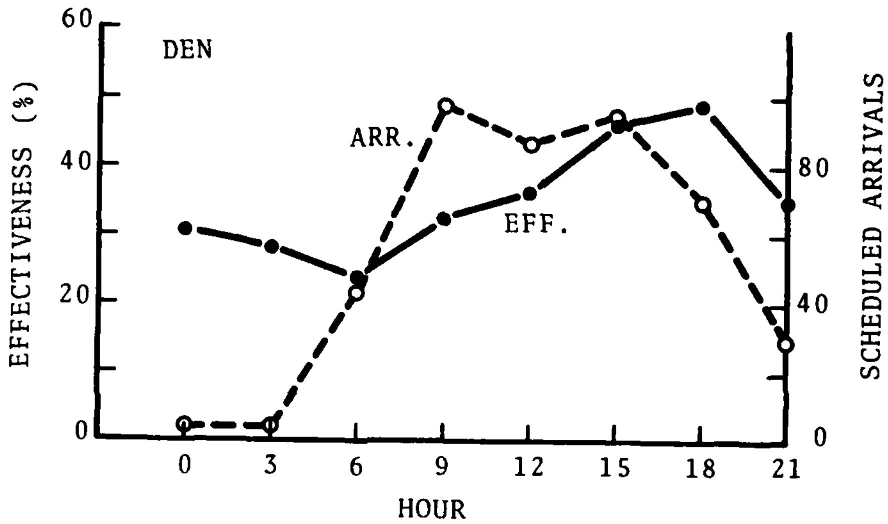
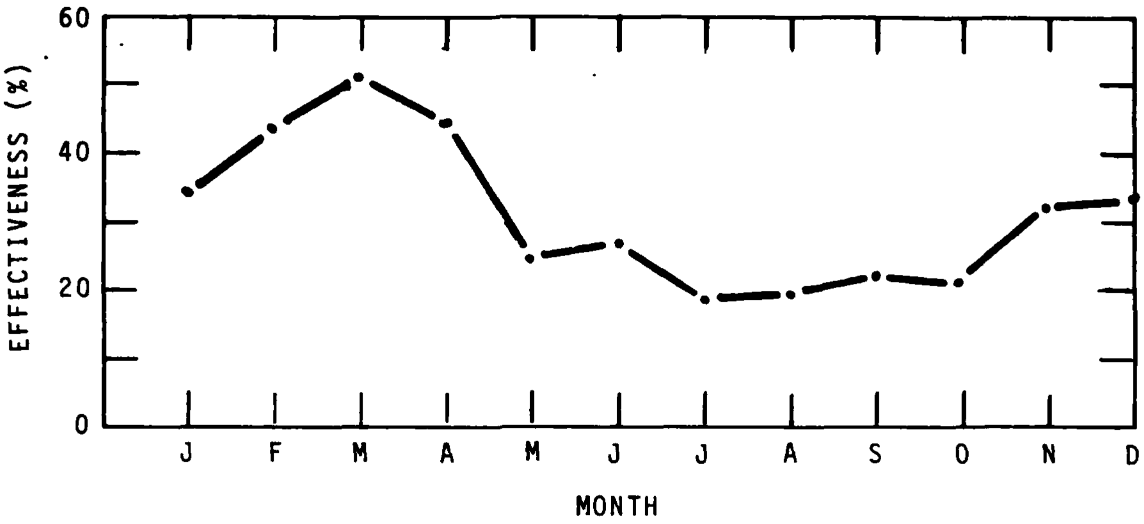


FIGURE 29. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR DEN



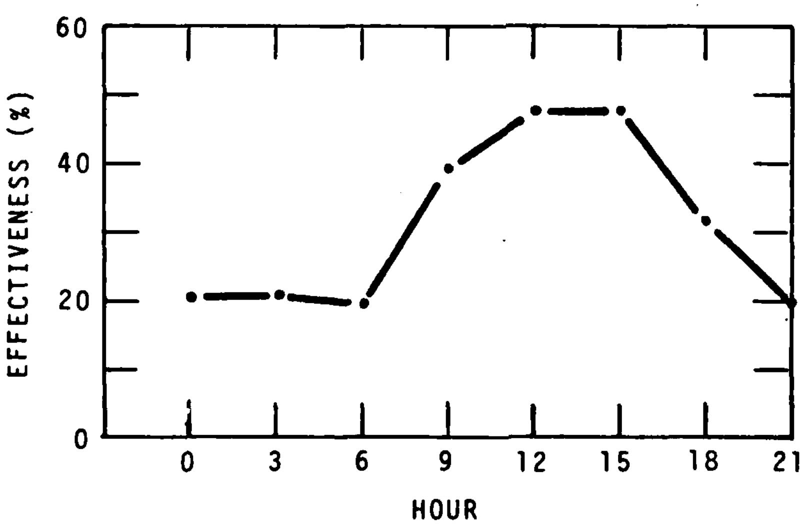


FIGURE 30. VAS EFFECTIVENESS FOR DFW RUNWAY 17/35

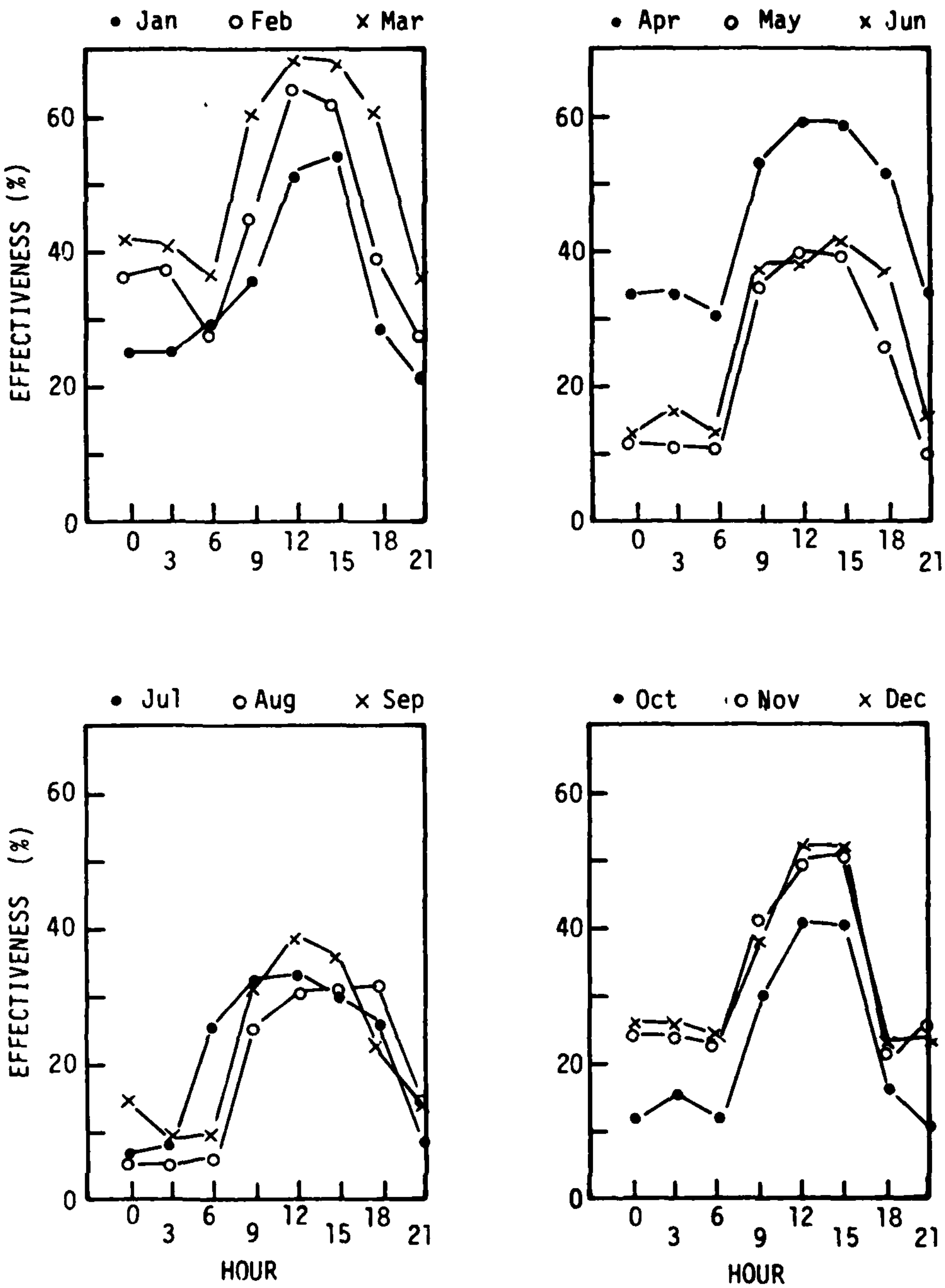
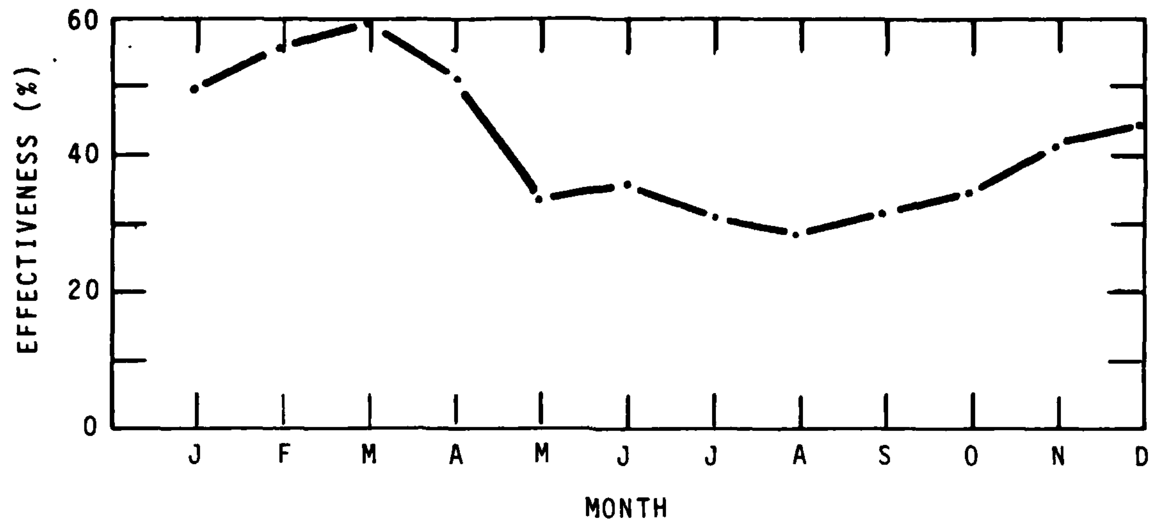


FIGURE 31. VAS EFFECTIVENESS FOR DFW RUNWAY 17/35 (CONCLUDED)



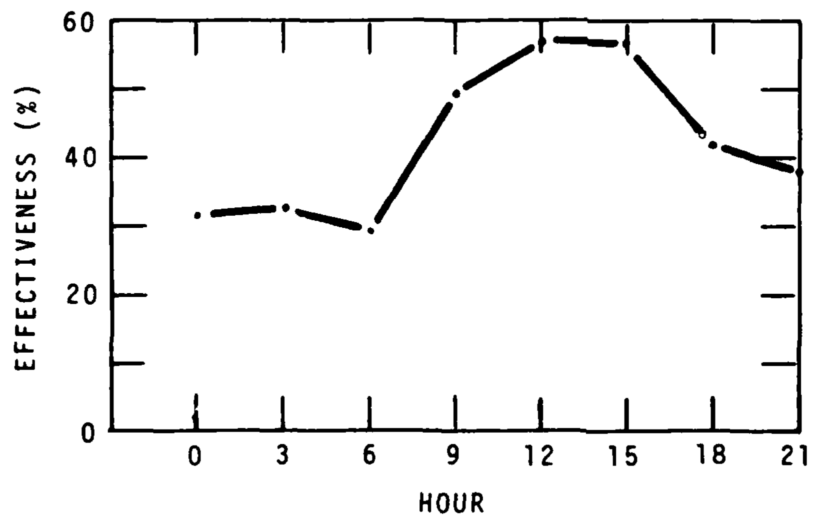


FIGURE 32. VAS EFFECTIVENESS FOR DFW RUNWAY 13/31

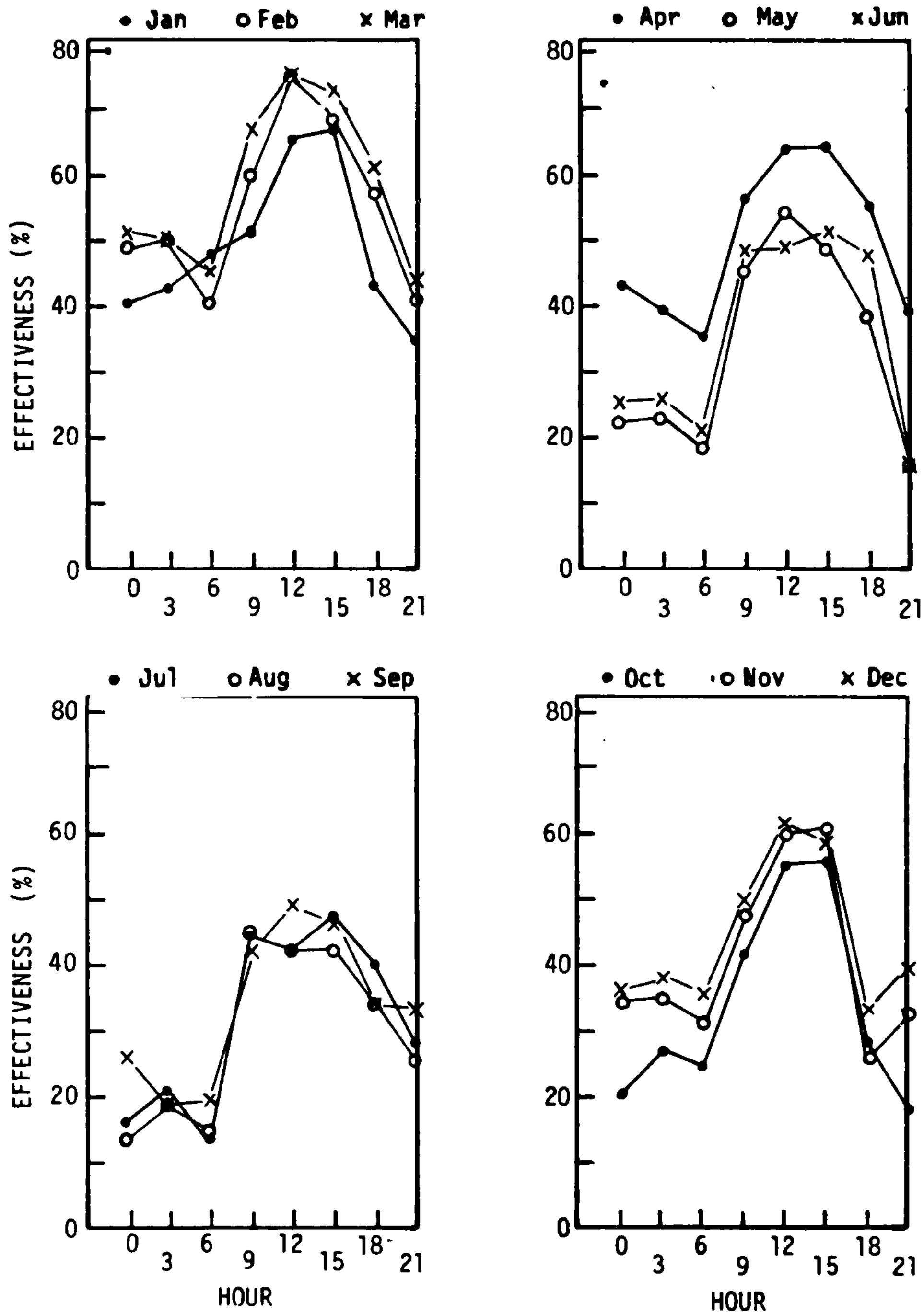


FIGURE 33. VAS EFFECTIVENESS FOR DFW RUNWAY 13/31 (CONCLUDED)

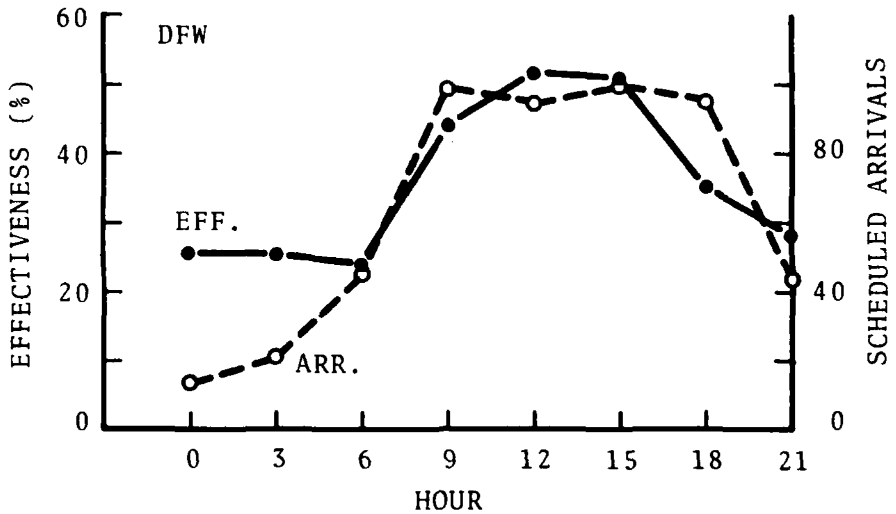


FIGURE 34. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR DFW

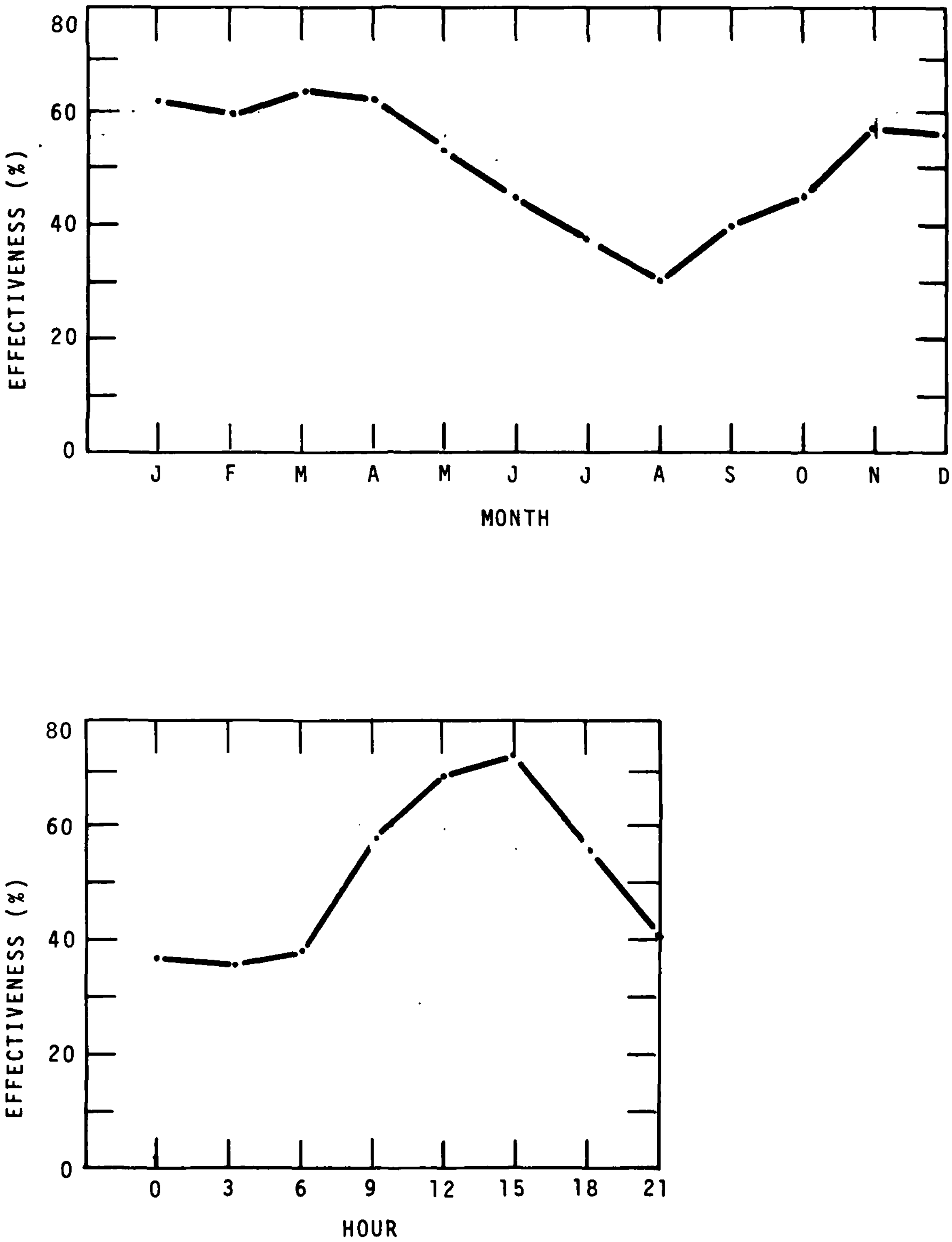


FIGURE 35. VAS EFFECTIVENESS FOR DTW RUNWAY 3/21

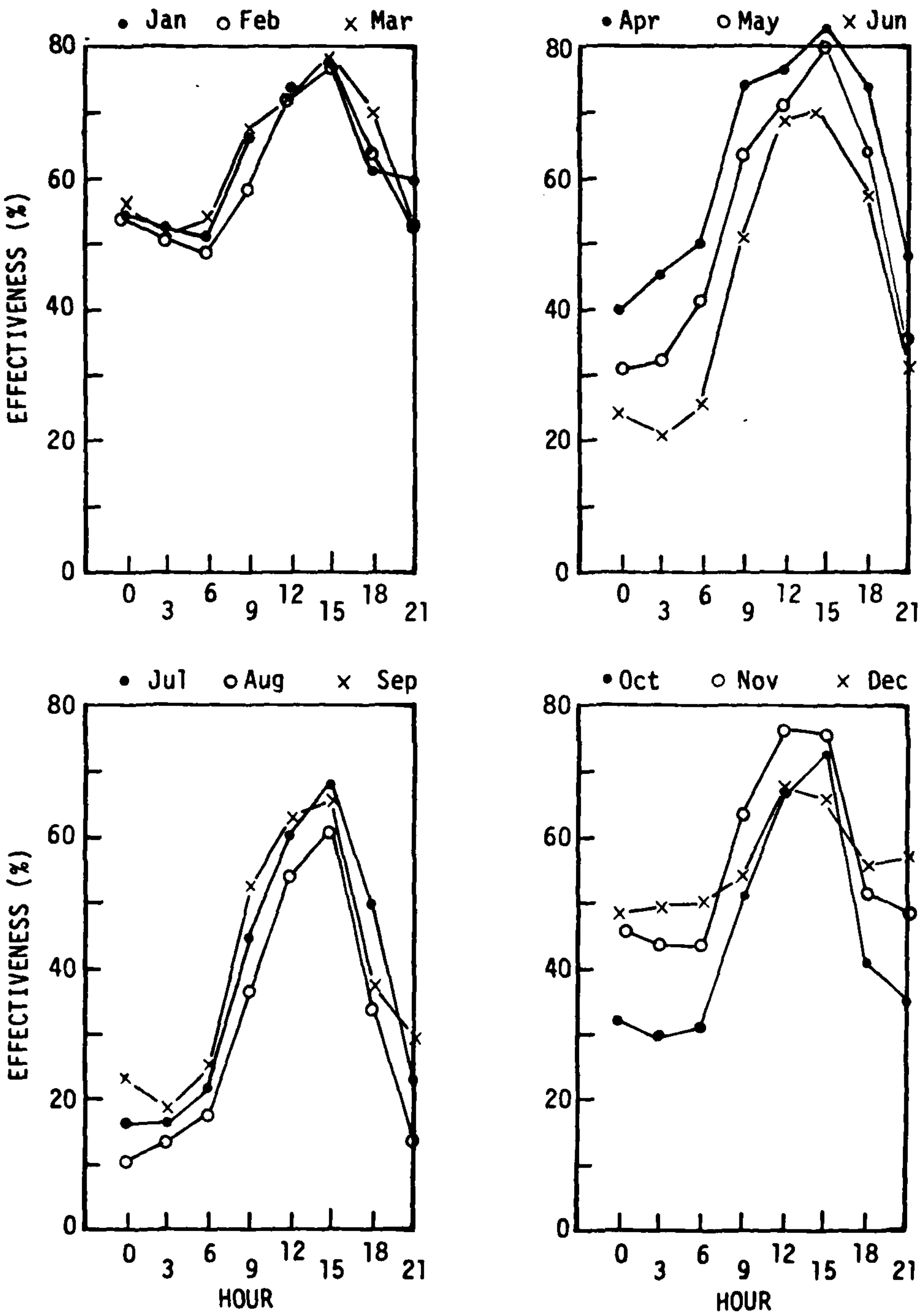


FIGURE 36. VAS EFFECTIVENESS FOR DTW RUNWAY 3/21 (CONCLUDED)

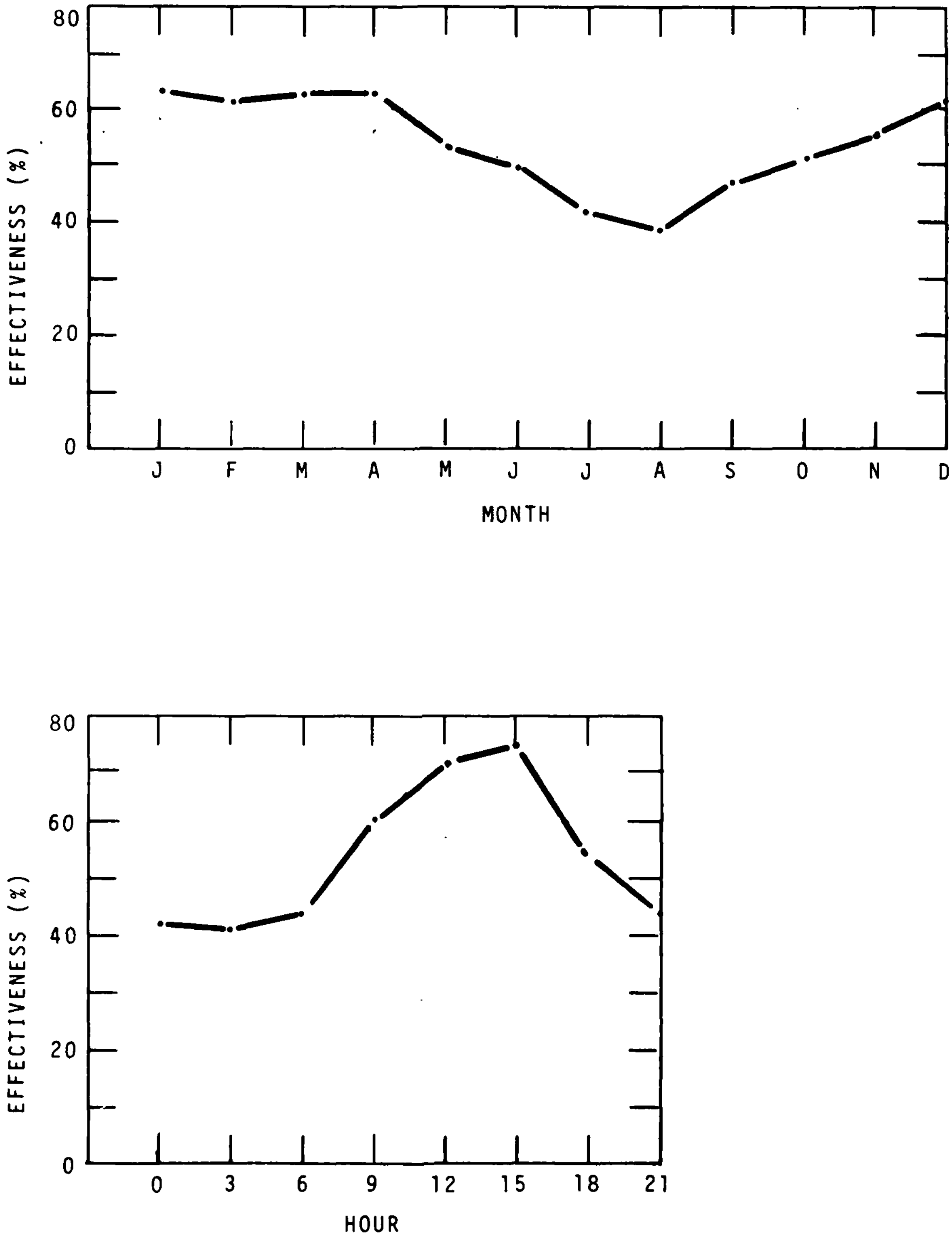


FIGURE 37. VAS EFFECTIVENESS FOR DTW RUNWAY 9/27

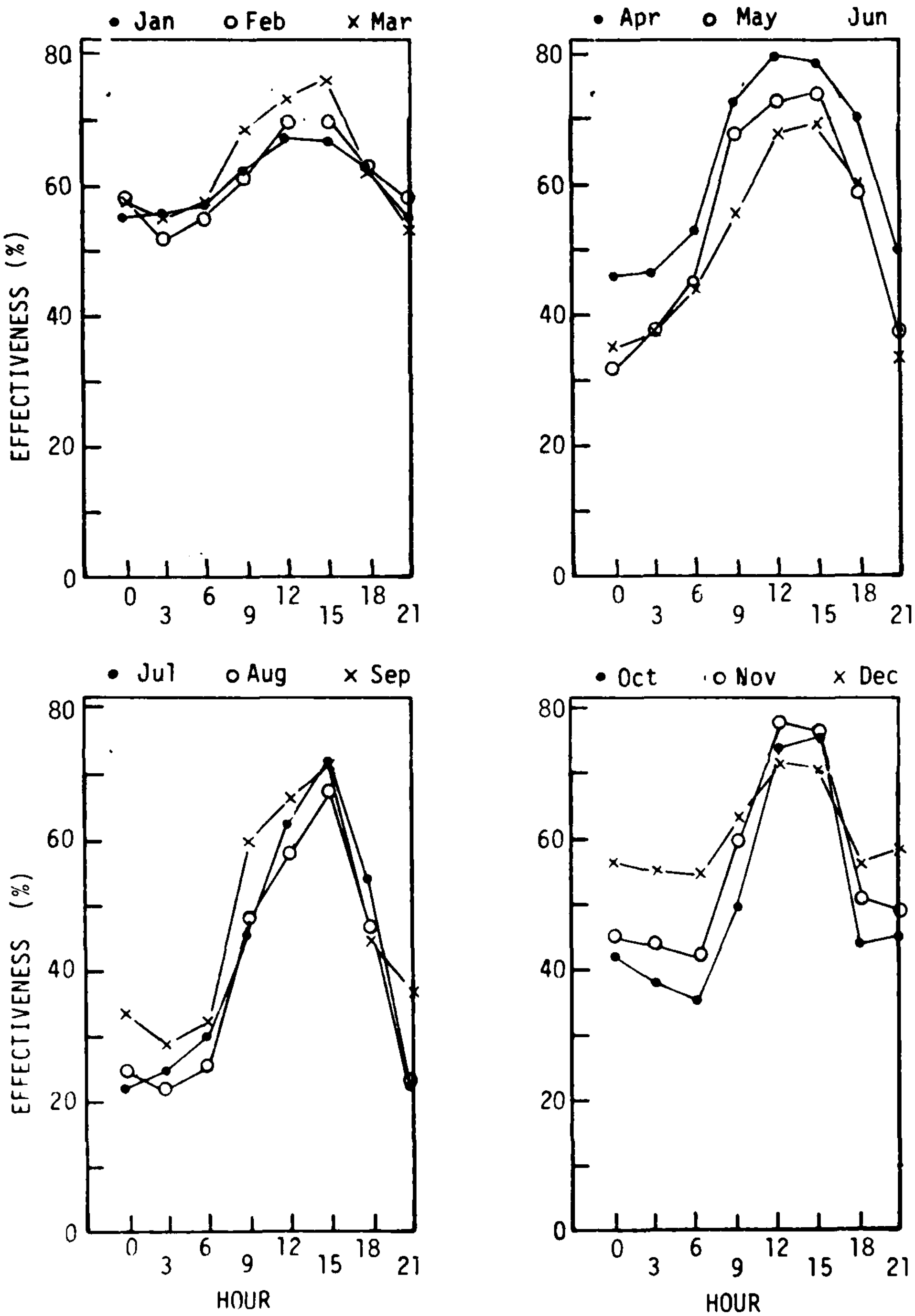


FIGURE 38. VAS EFFECTIVENESS FOR DTW RUNWAY 9/27 (CONCLUDED)

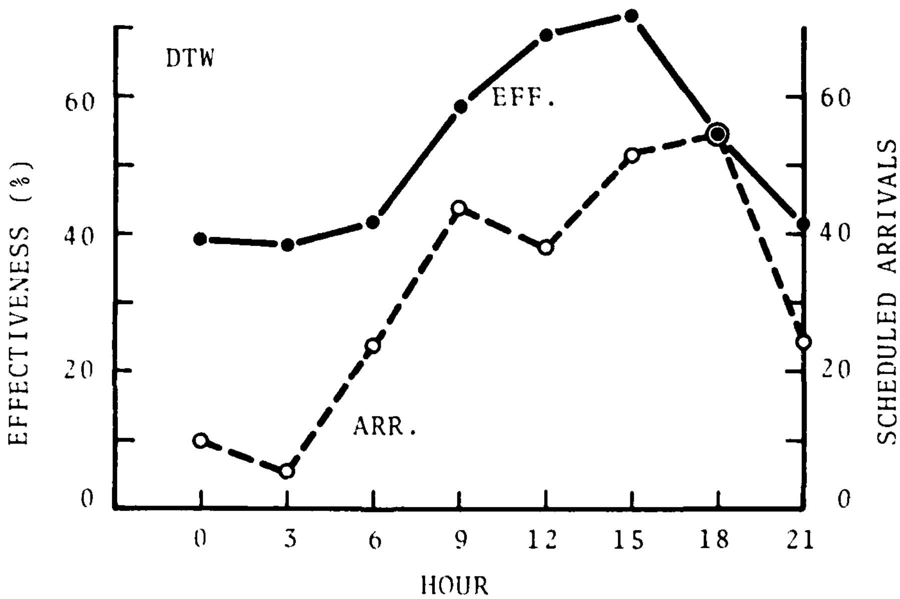
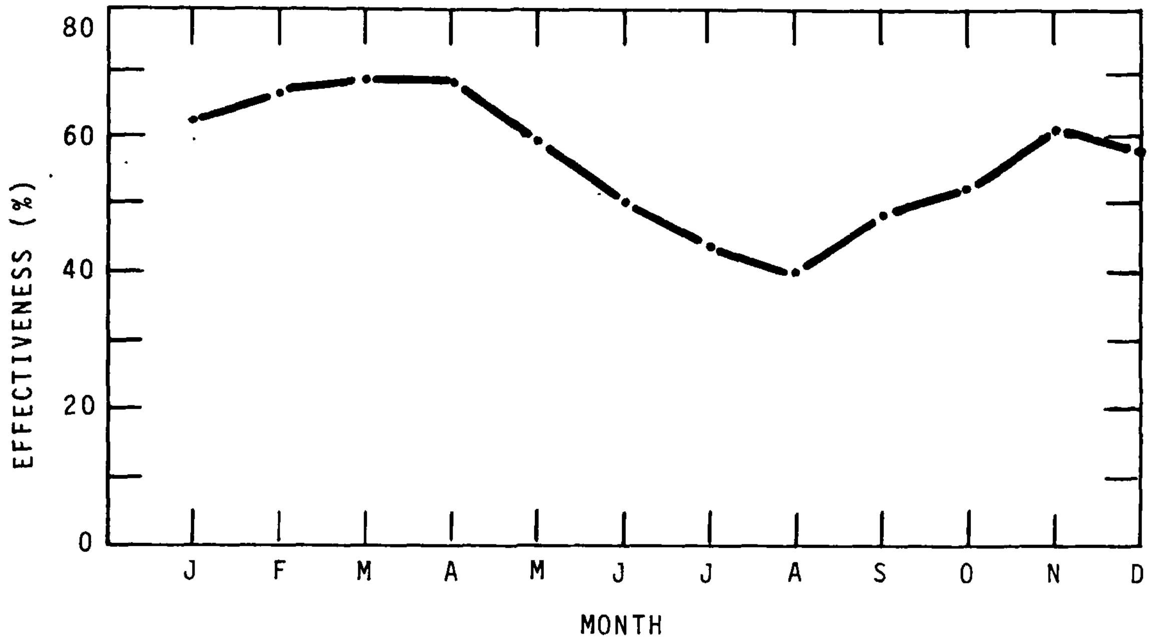


FIGURE 39. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR DTW



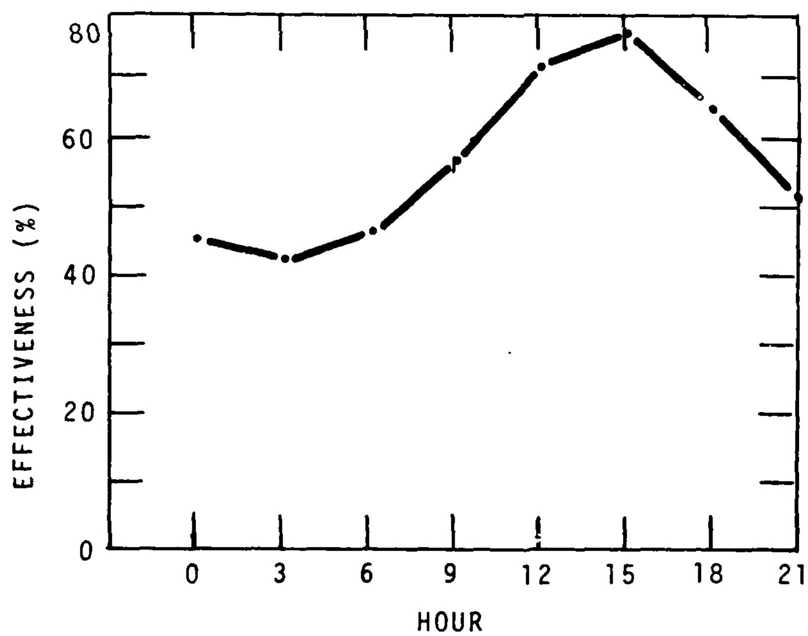


FIGURE 40. VAS EFFECTIVENESS FOR JFK RUNWAY 4/22

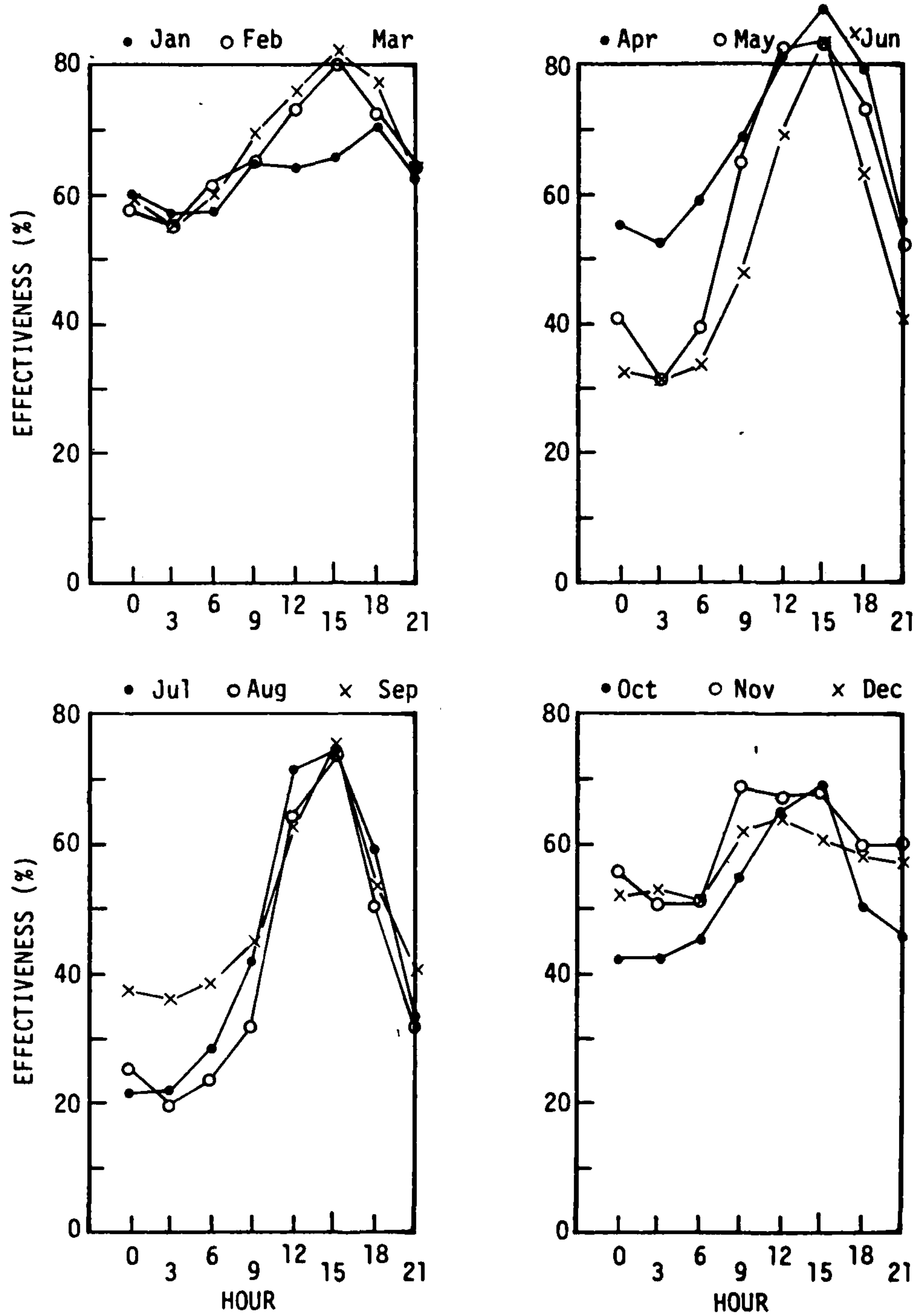
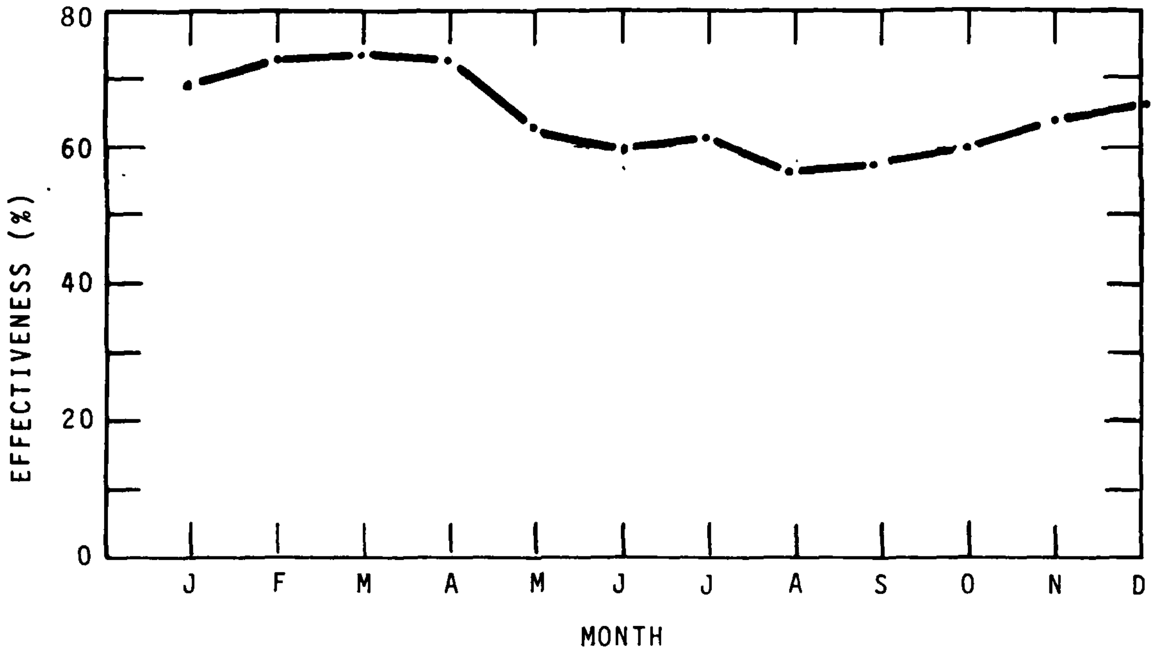


FIGURE 41. VAS EFFECTIVENESS FOR JFK RUNWAY 4/22 (CONCLUDED)



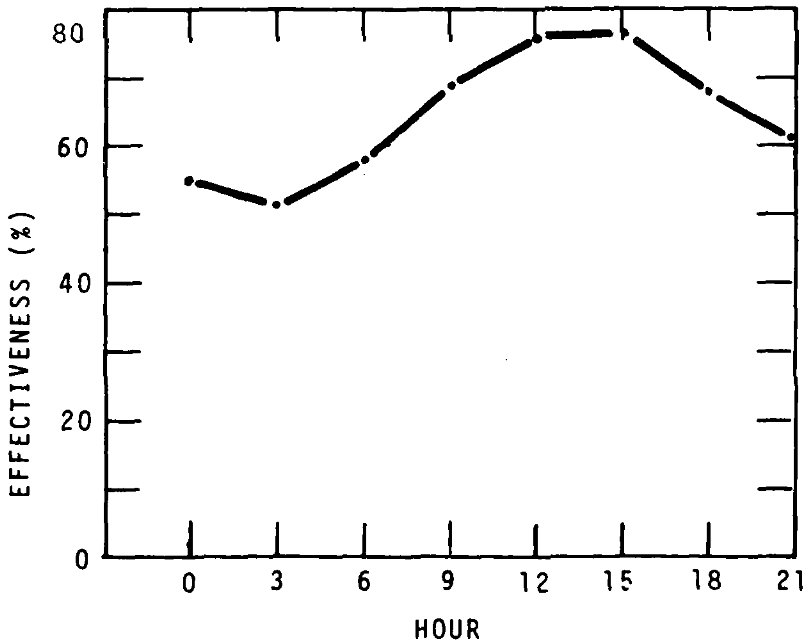


FIGURE 42. VAS EFFECTIVENESS FOR JFK RUNWAY 13/31

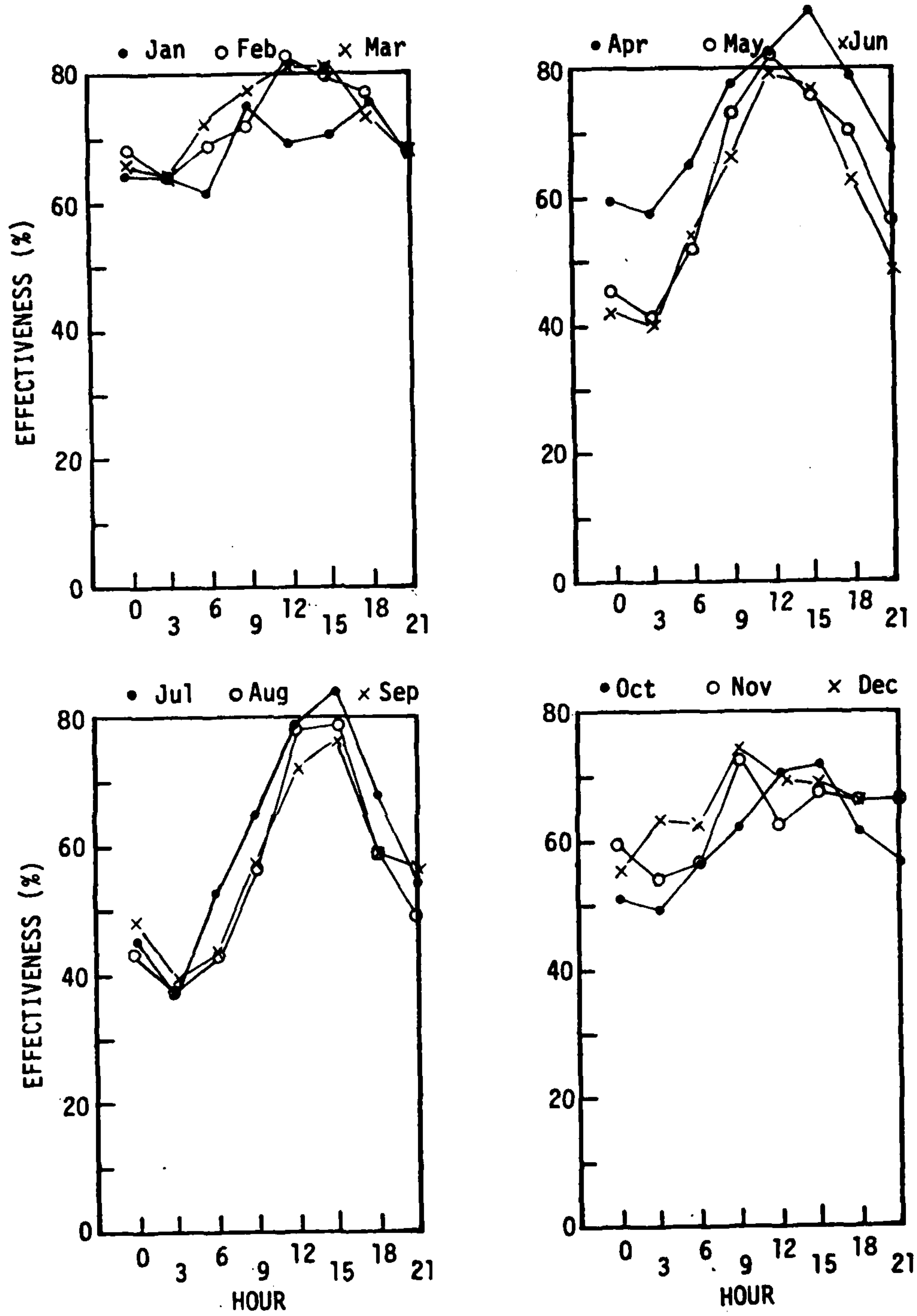


FIGURE 43. VAS EFFECTIVENESS FOR JFK RUNWAY 13/31 (CONCLUDED)

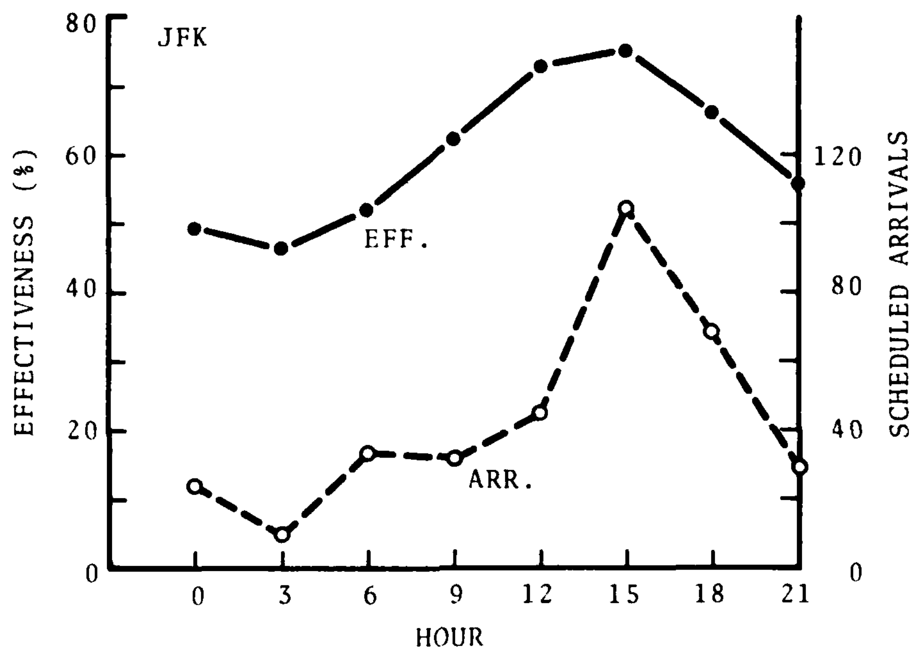


FIGURE 44. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR JFK

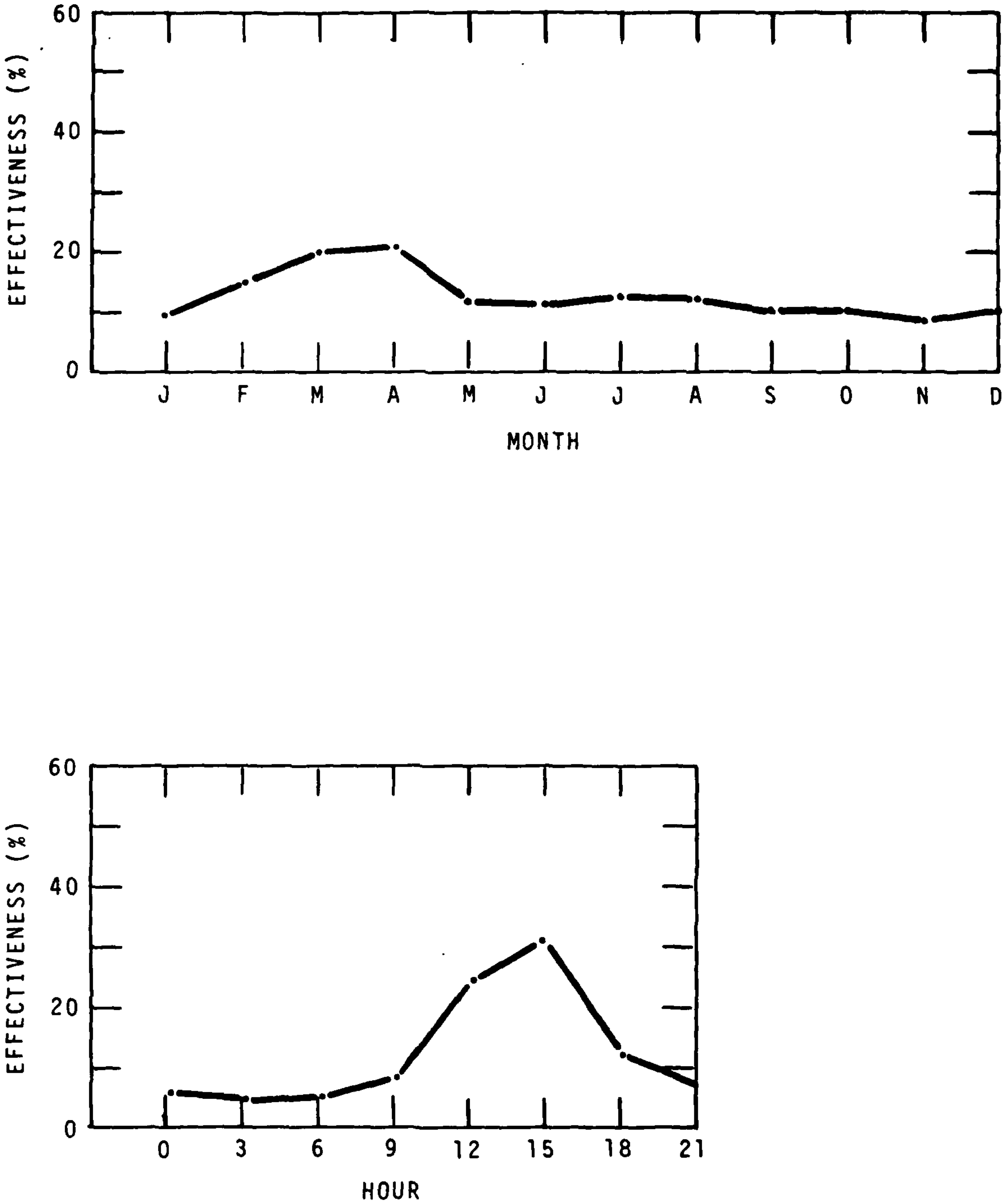


FIGURE 45. VAS EFFECTIVENESS FOR LAX RUNWAY 6/24

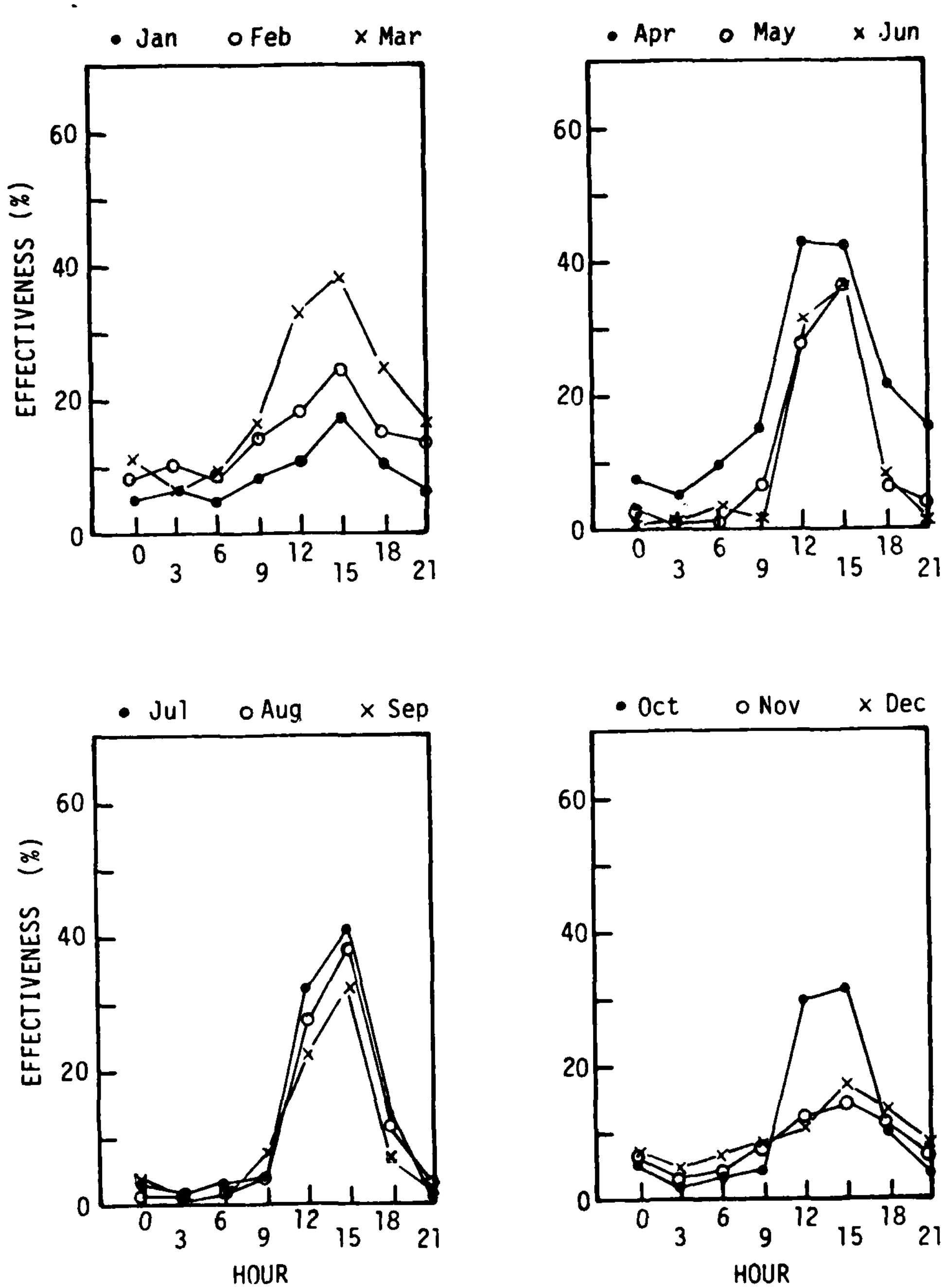


FIGURE 46. VAS EFFECTIVENESS FOR LAX RUNWAY 6/24 (CONCLUDED)

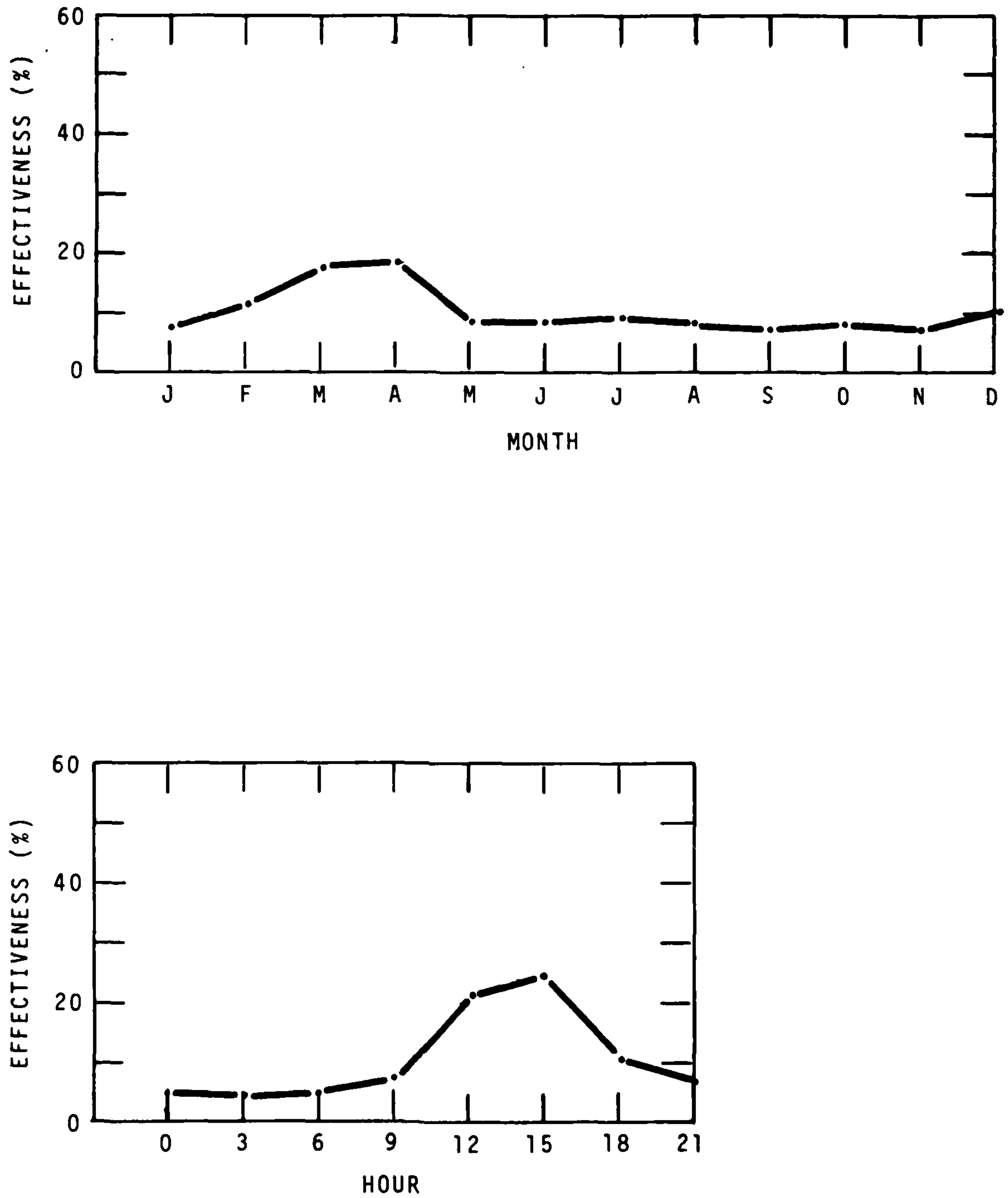


FIGURE 47. VAS EFFECTIVENESS FOR LAX RUNWAY 7/25

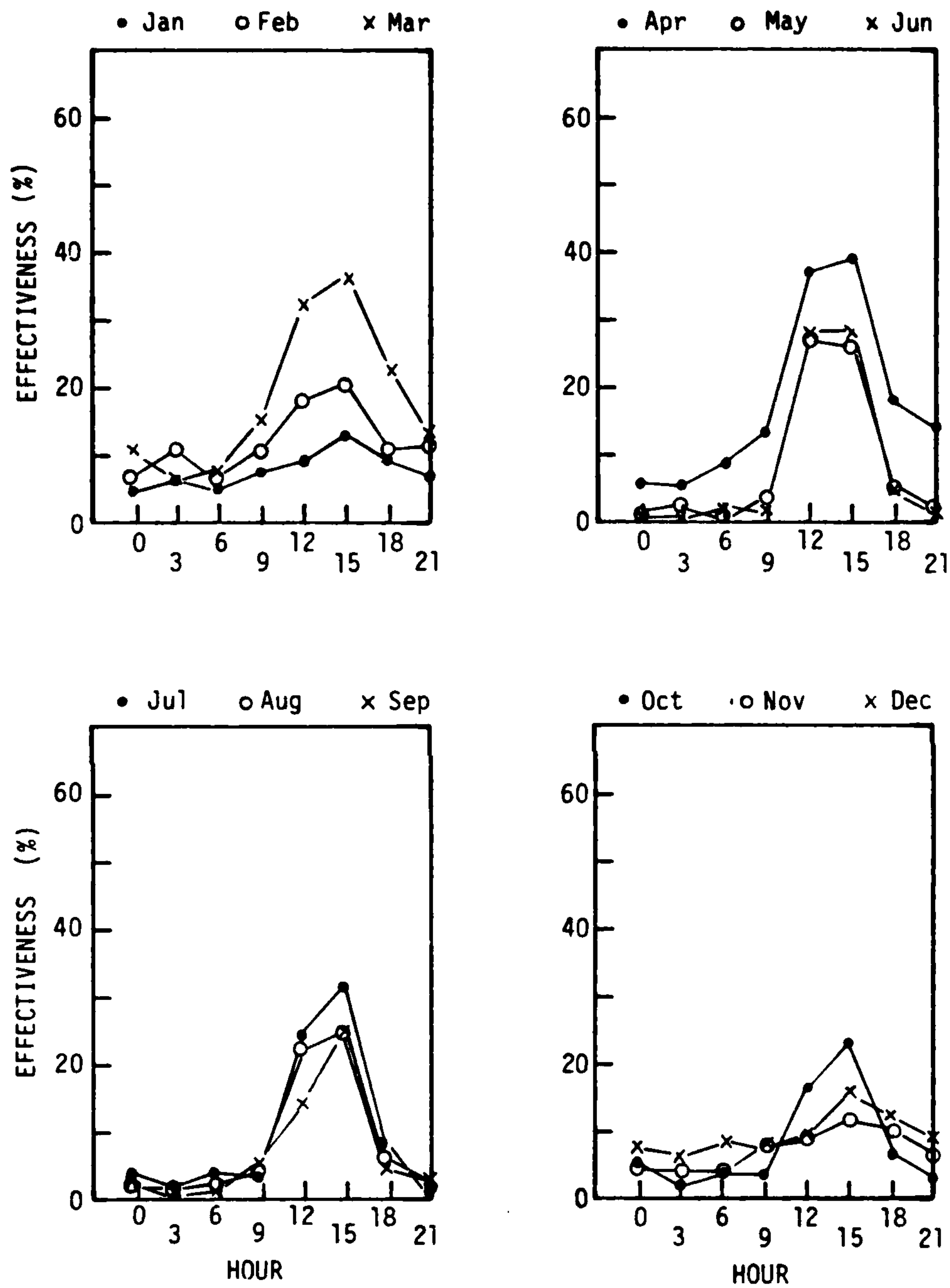


FIGURE 48. VAS EFFECTIVENESS FOR LAX RUNWAY 7/25 (CONCLUDED)

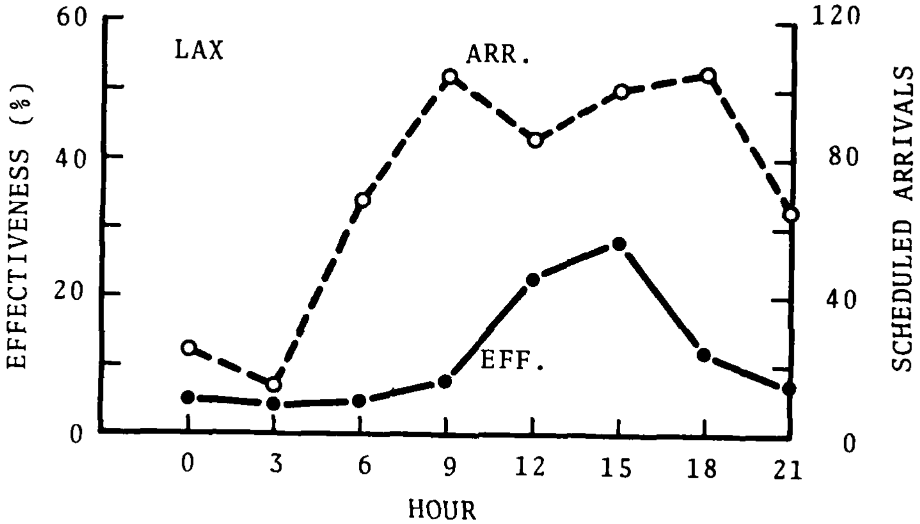
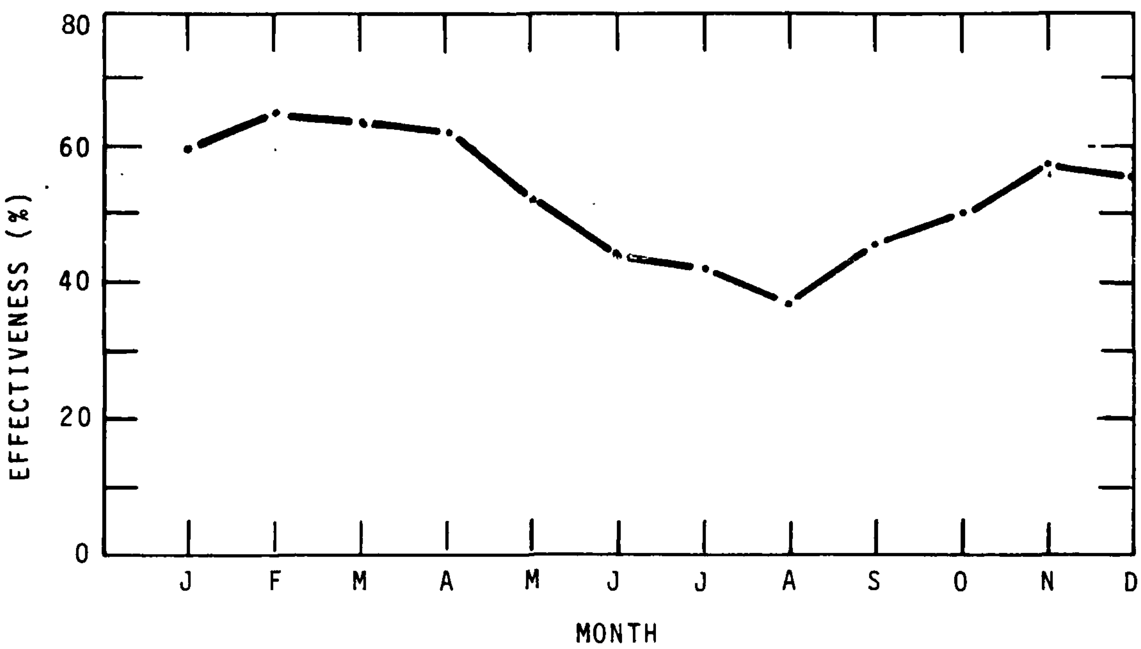


FIGURE 49. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR LAX



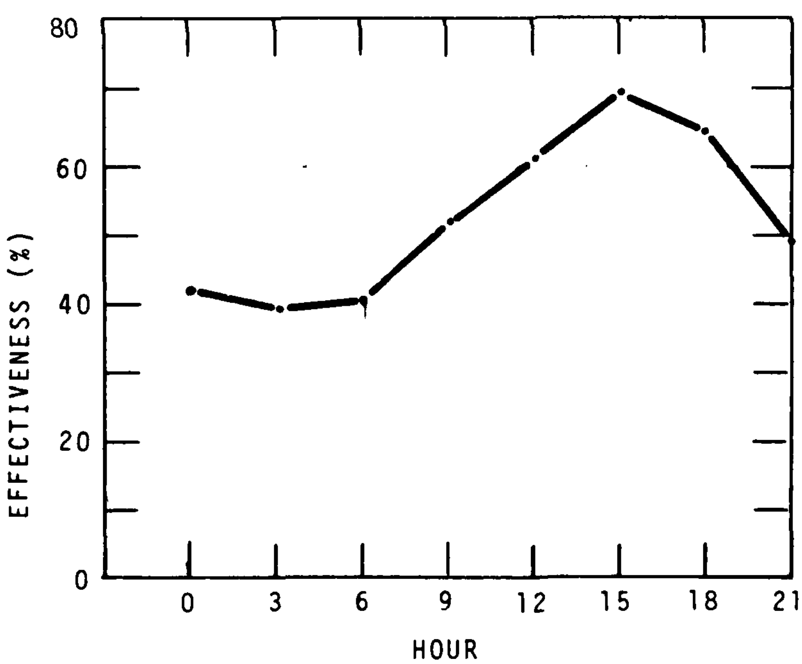


FIGURE 50. VAS EFFECTIVENESS FOR LGA RUNWAY 4/22

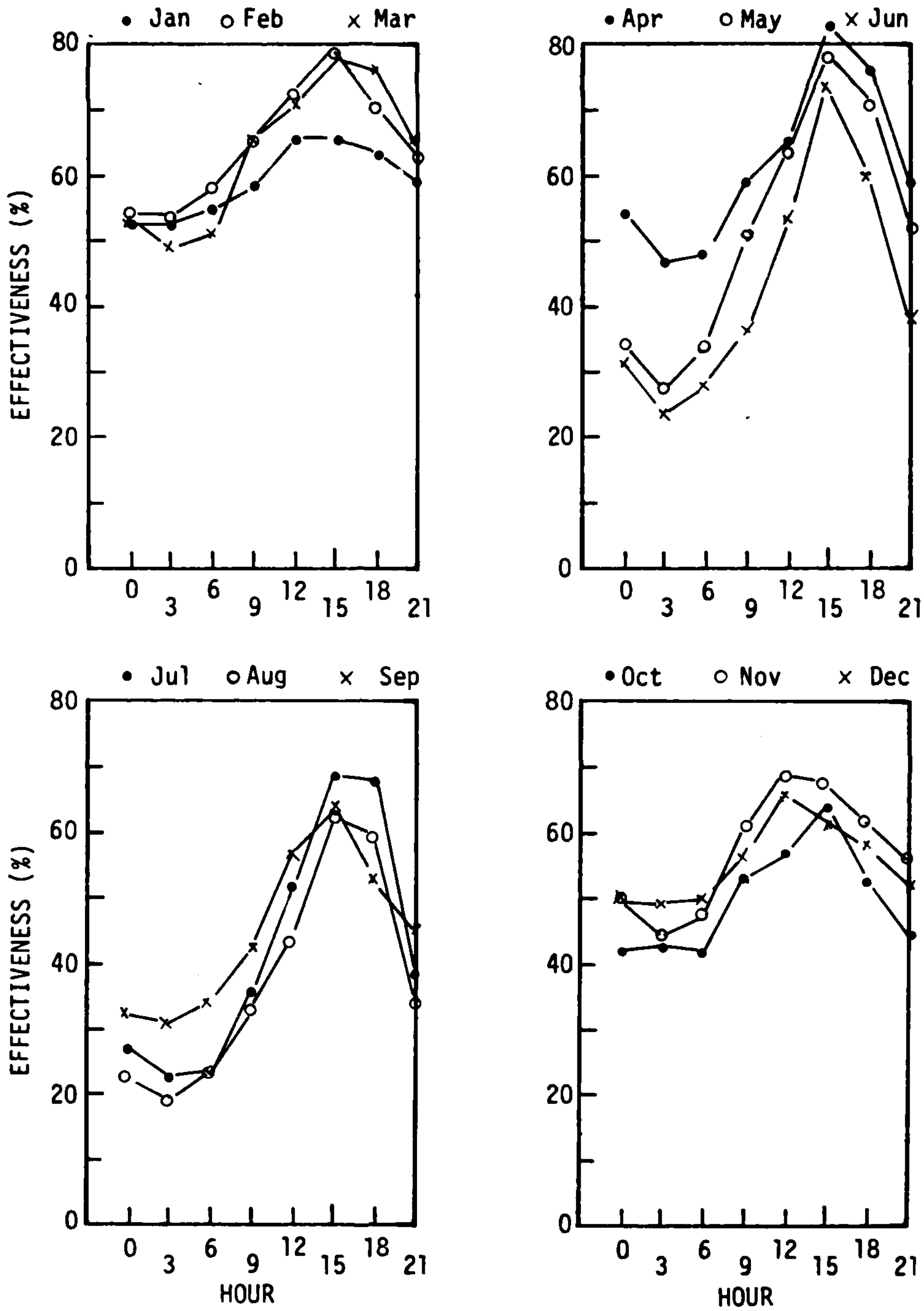
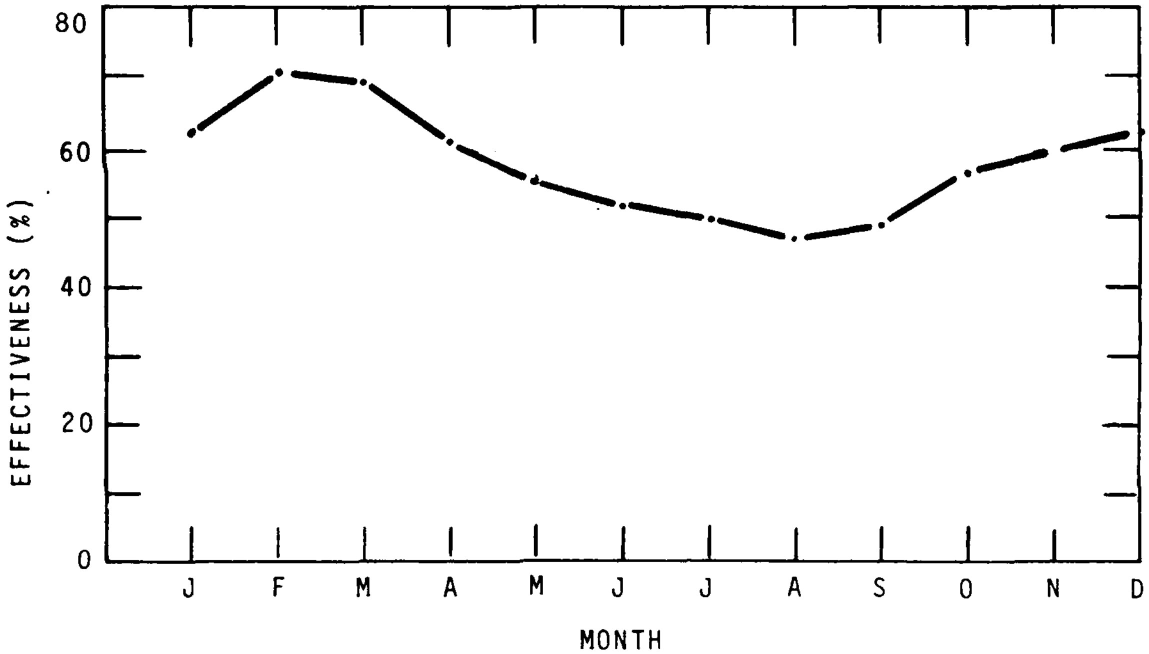


FIGURE 51. VAS EFFECTIVENESS FOR LGA RUNWAY 4/22 (CONCLUDED)



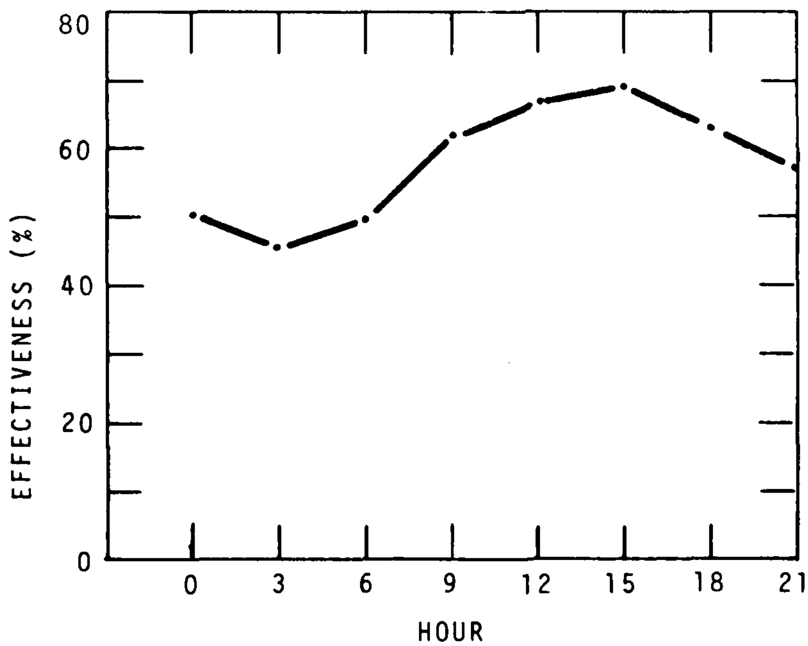


FIGURE 52. VAS EFFECTIVENESS FOR LGA RUNWAY 13/31

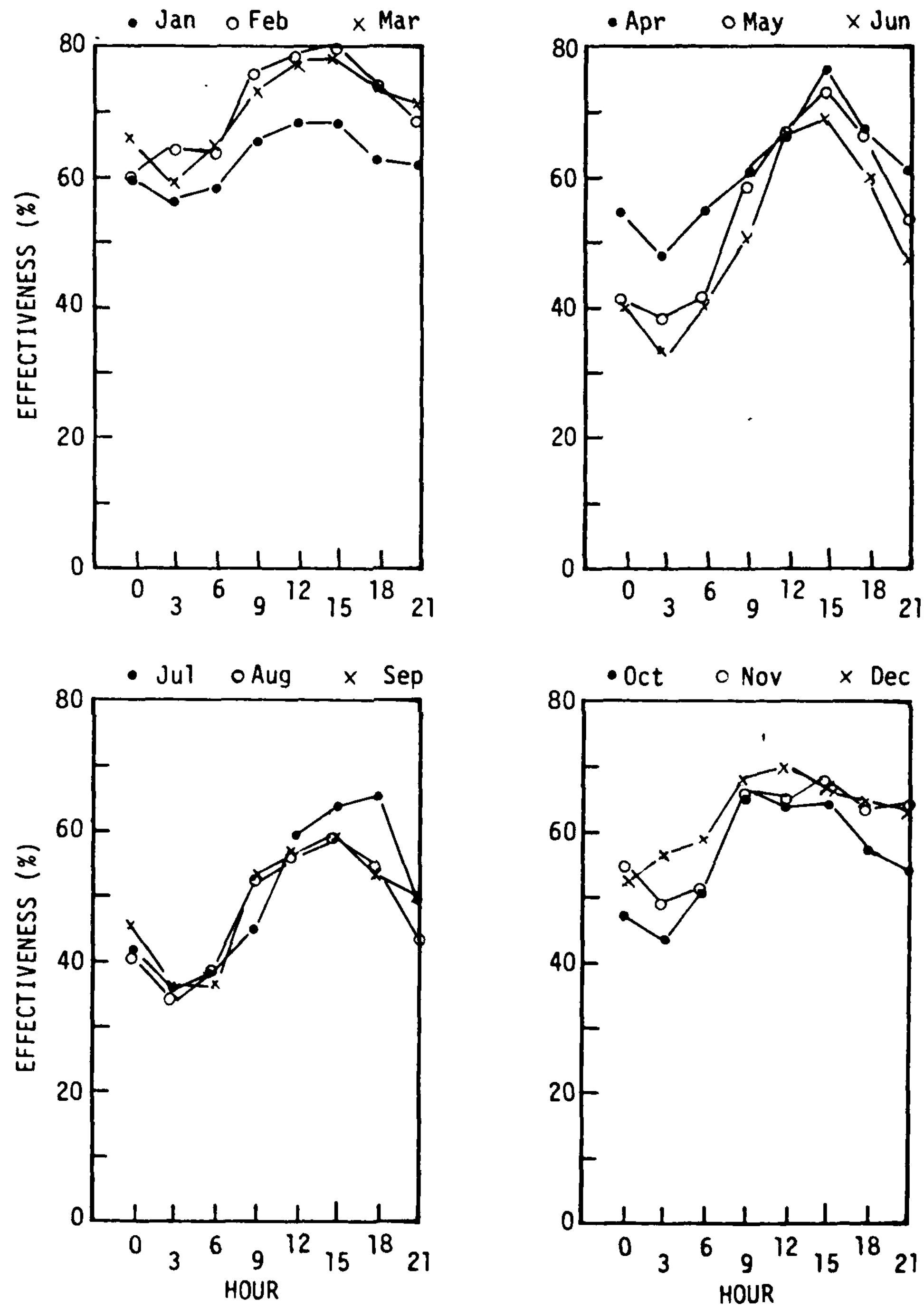


FIGURE 53. VAS EFFECTIVENESS FOR LGA RUNWAY 13/31 (CONCLUDED)

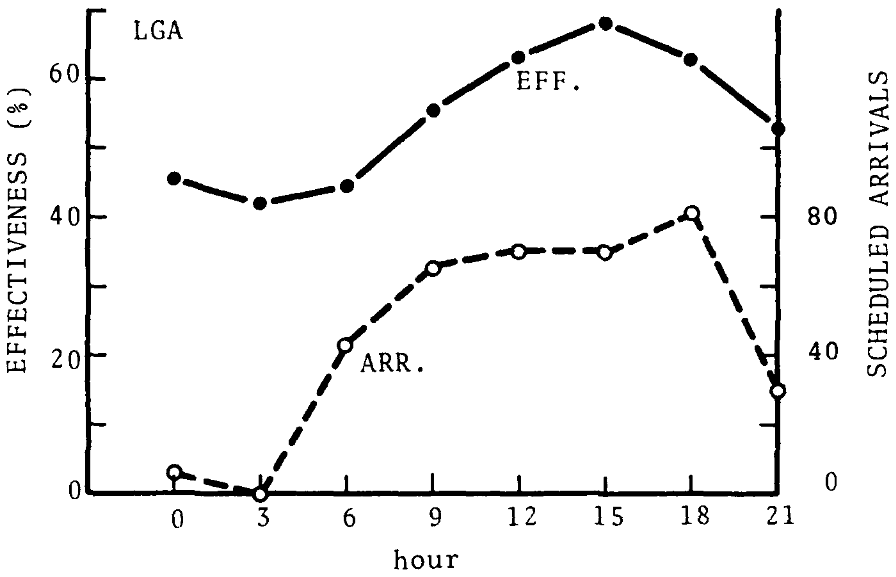
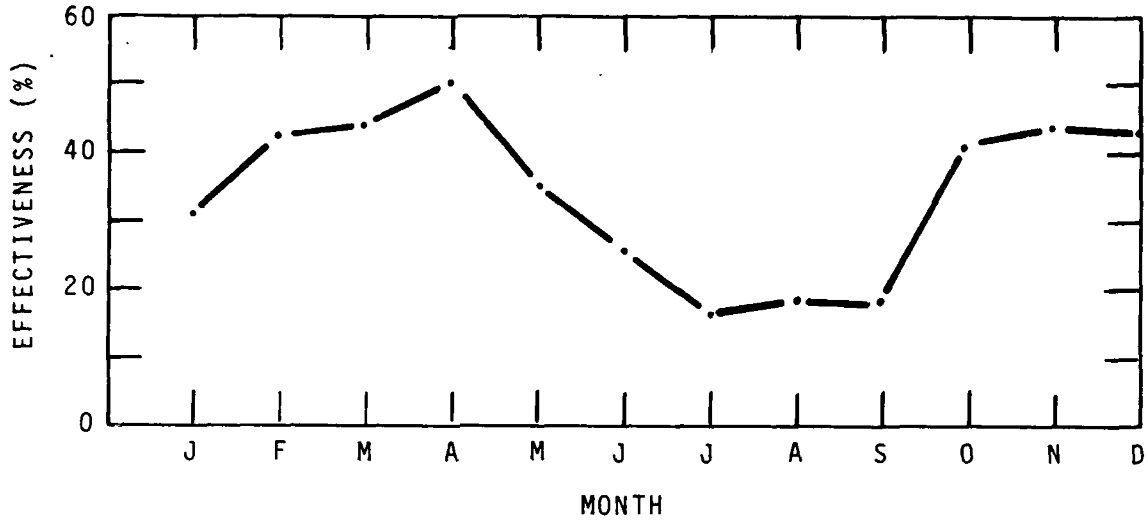


FIGURE 54. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR LGA



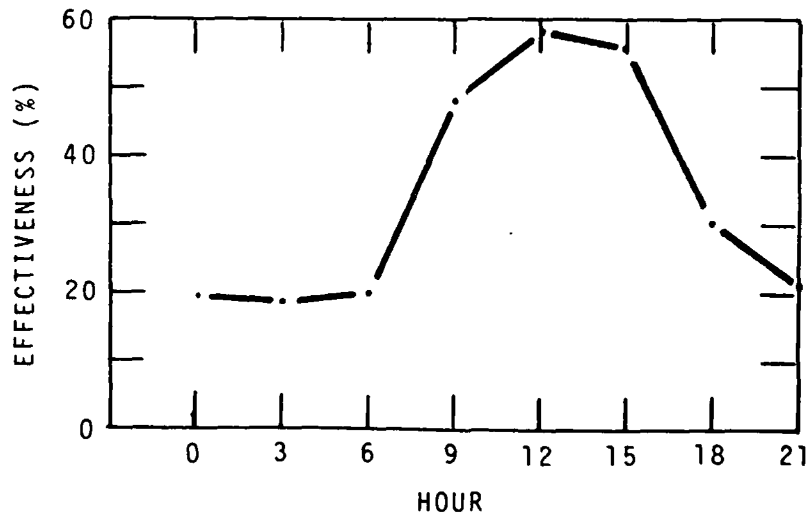


FIGURE 55. VAS EFFECTIVENESS FOR MIA RUNWAY 9/27

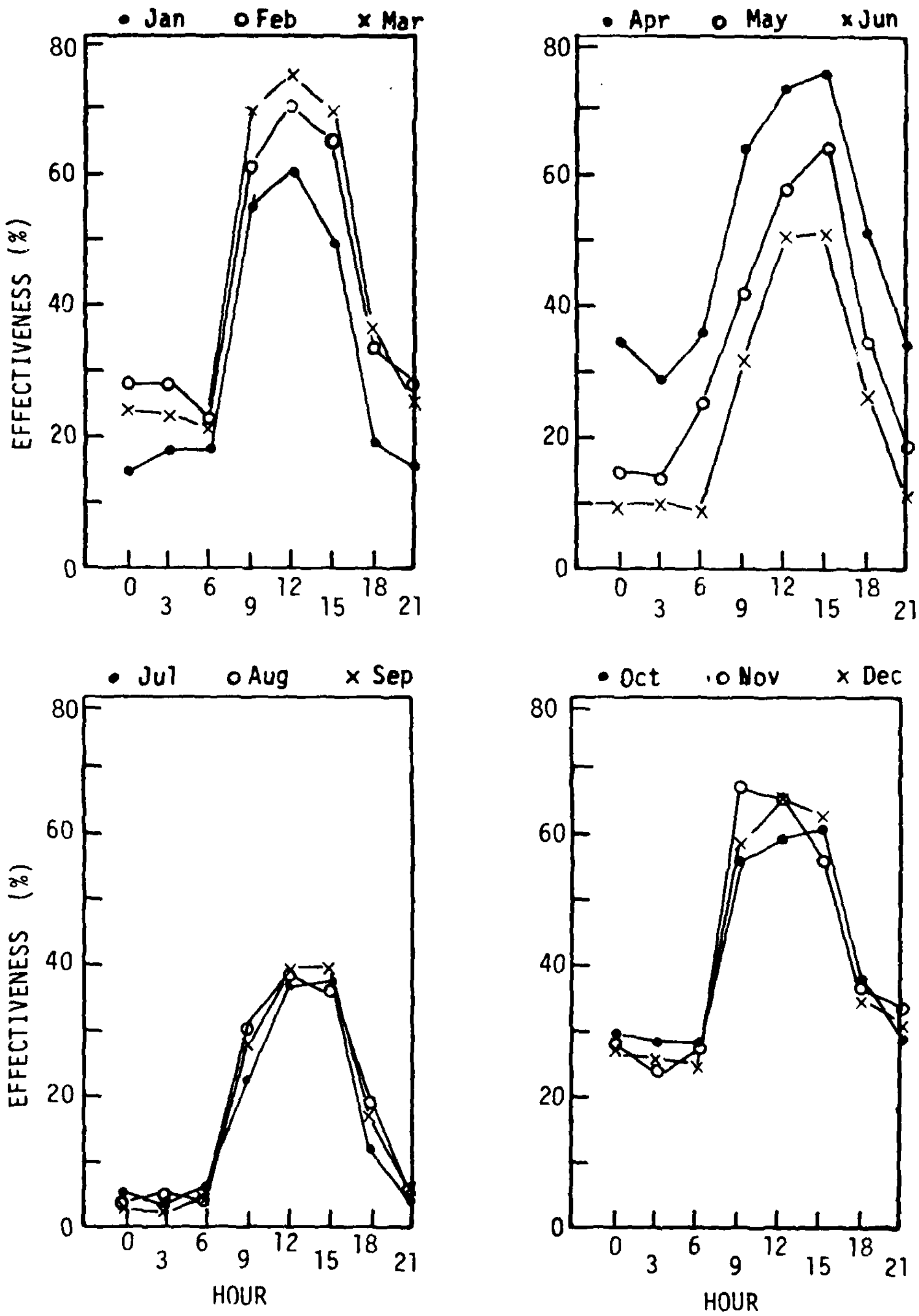


FIGURE 56. VAS EFFECTIVENESS FOR MIA RUNWAY 9/27 (CONCLUDED)

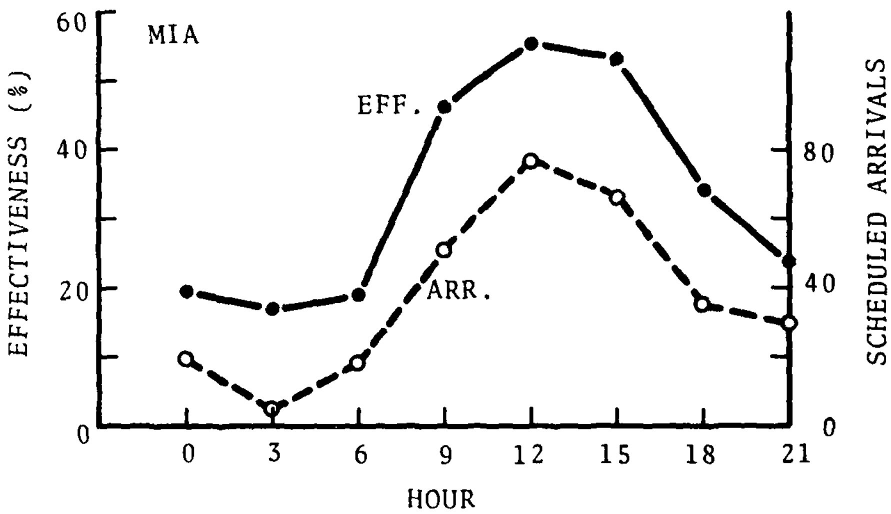


FIGURE 57. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR MIA

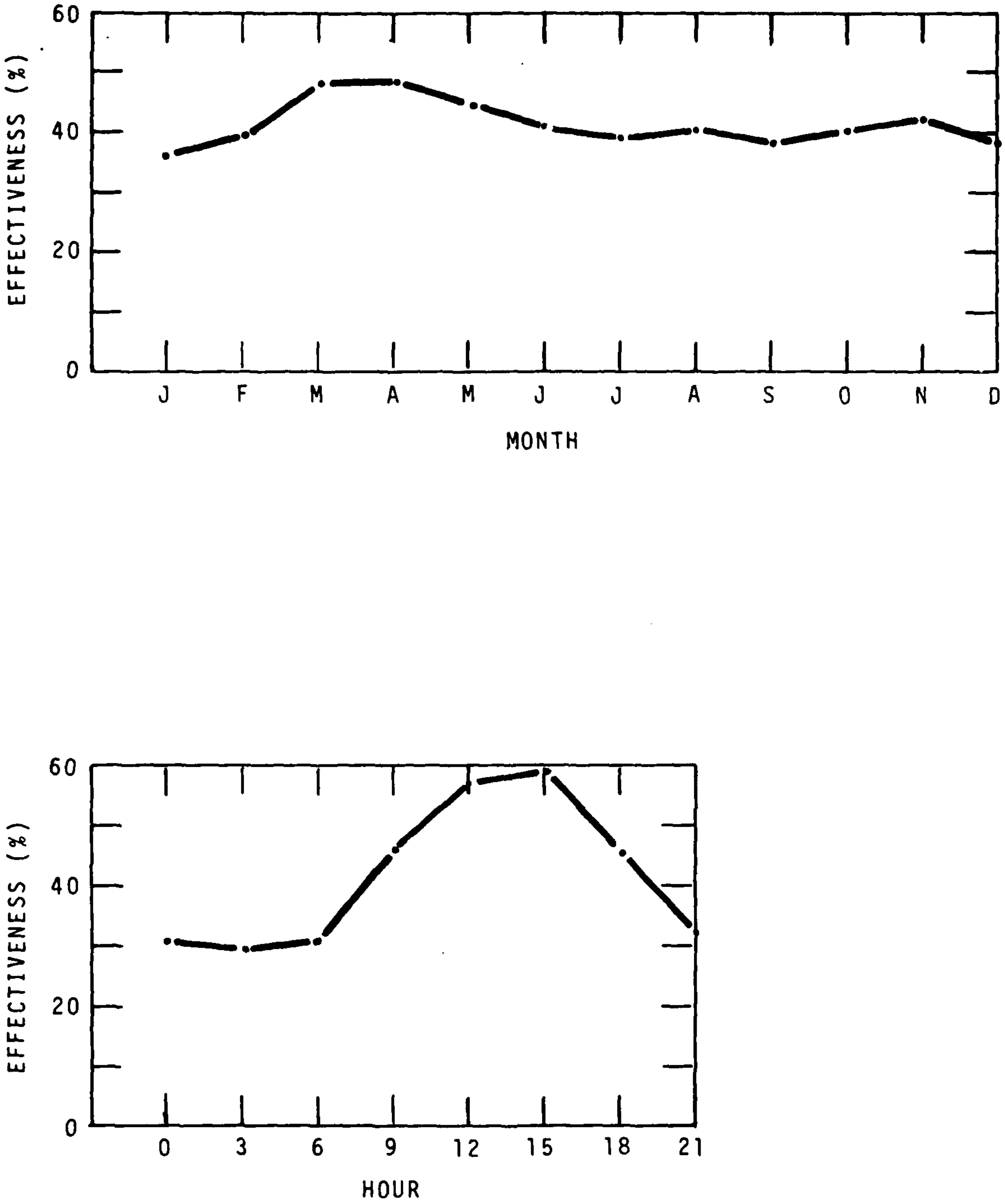


FIGURE 58. VAS EFFECTIVENESS FOR MSP RUNWAY 11/29

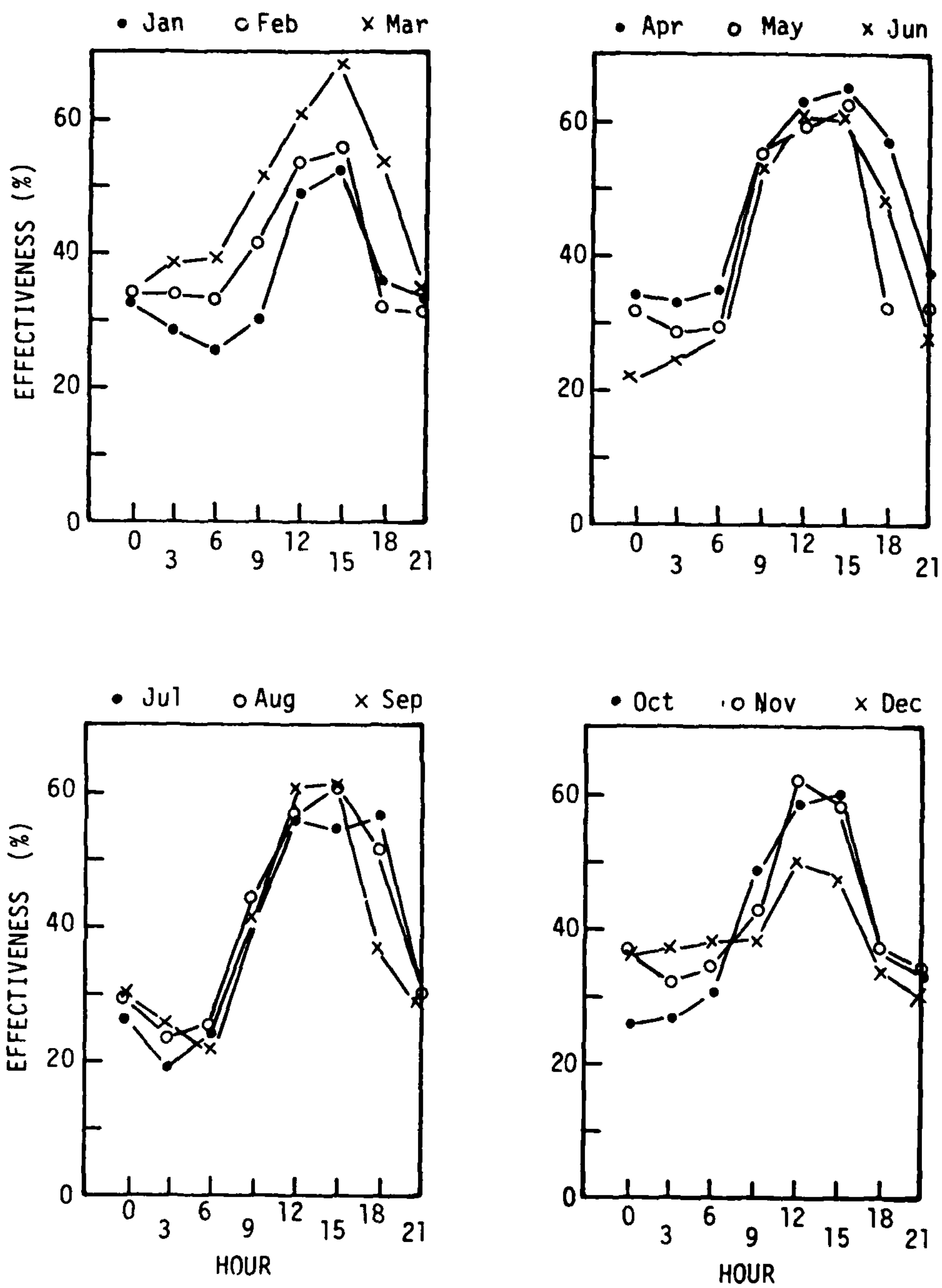
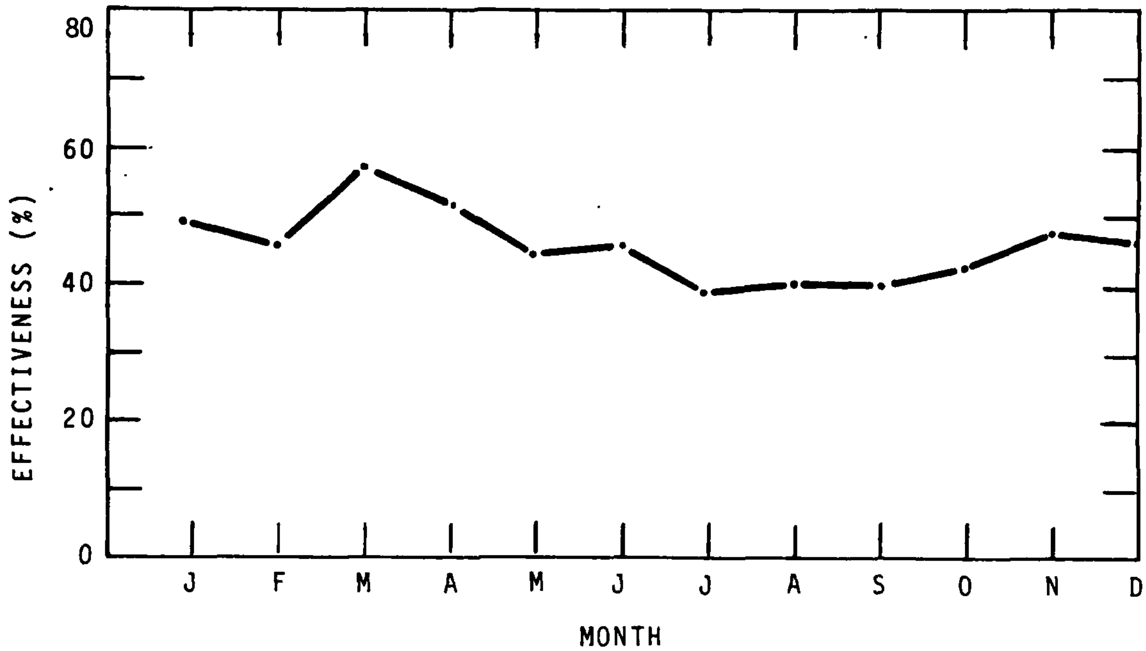


FIGURE 59. VAS EFFECTIVENESS FOR MSP RUNWAY 11/29 (CONCLUDED)



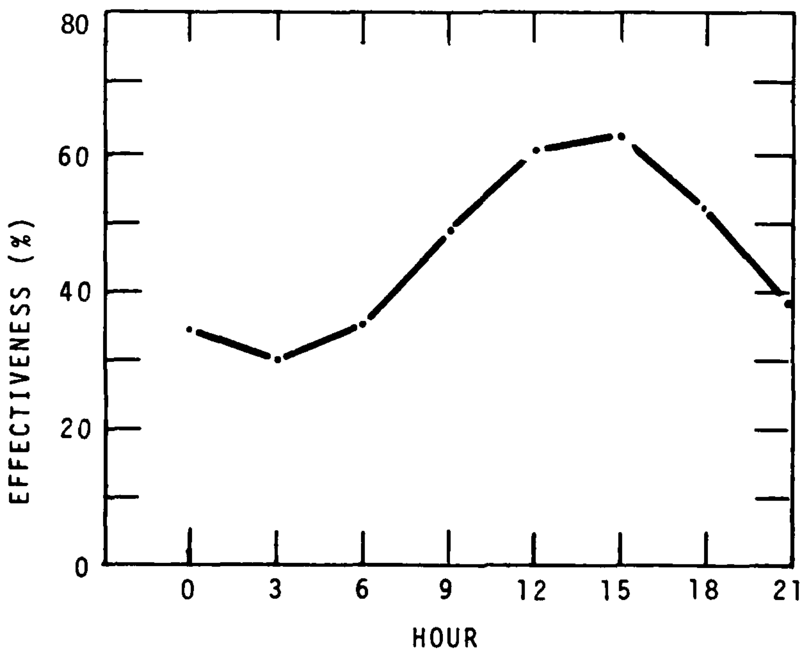


FIGURE 60. VAS EFFECTIVENESS FOR MSP RUNWAY 4/22

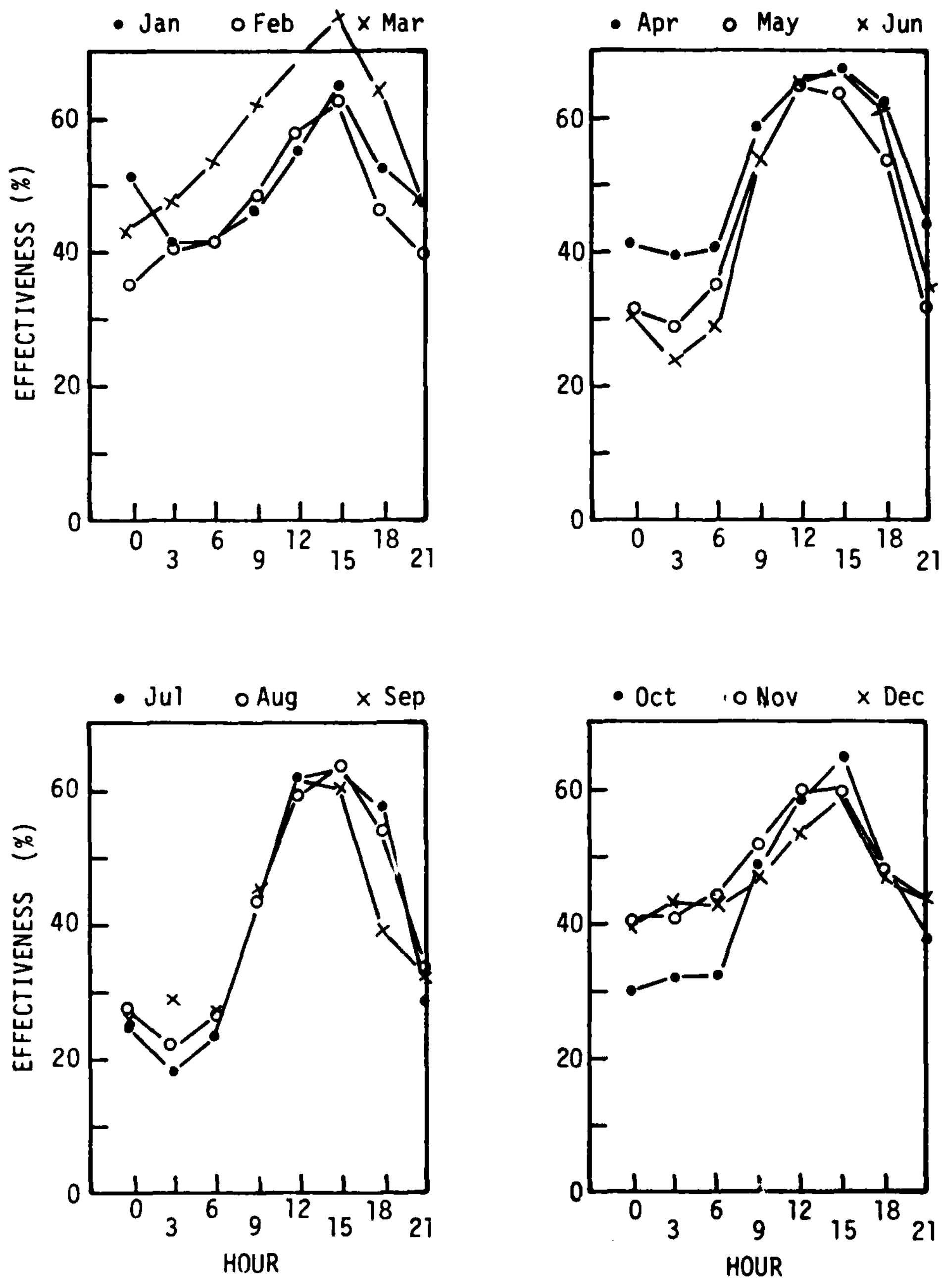


FIGURE 61. VAS EFFECTIVENESS FOR MSP RUNWAY 4/22 (CONCLUDED)

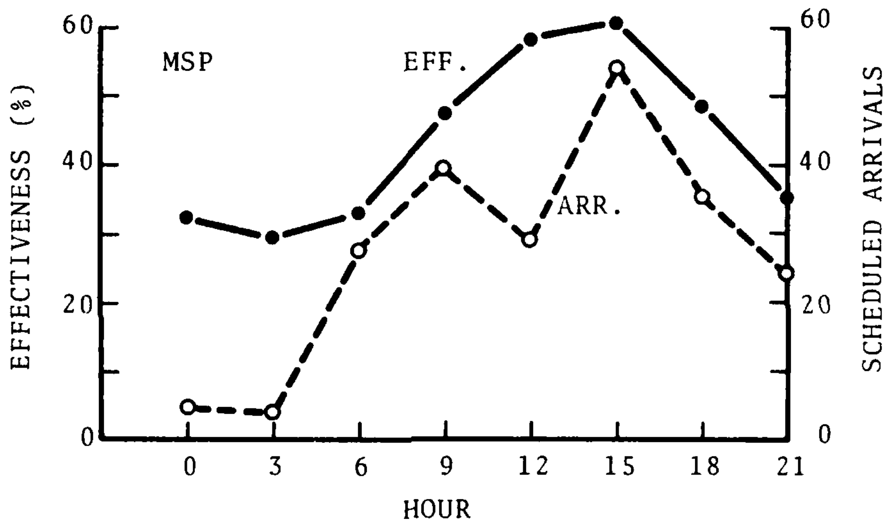
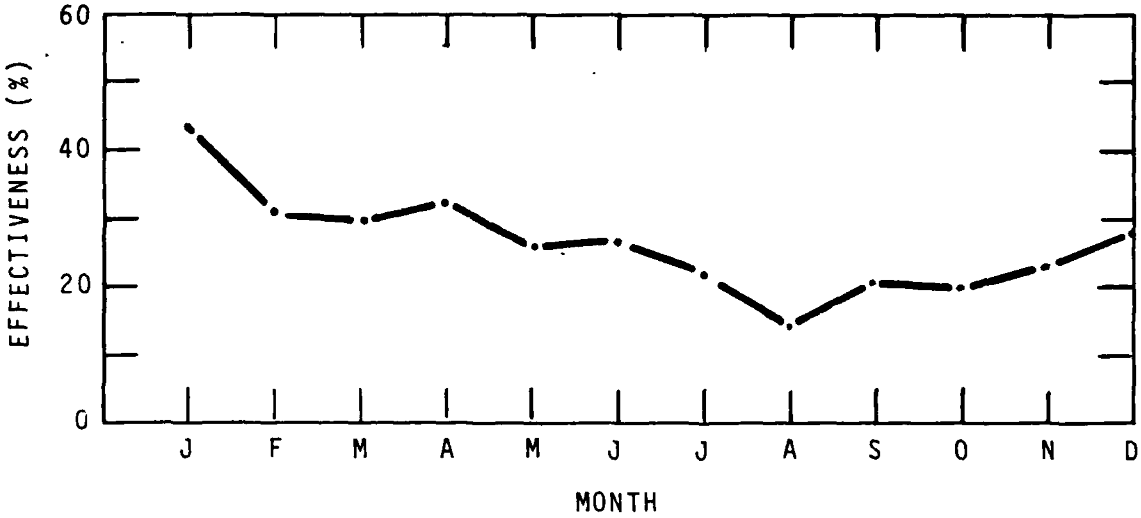


FIGURE 62. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR MSP



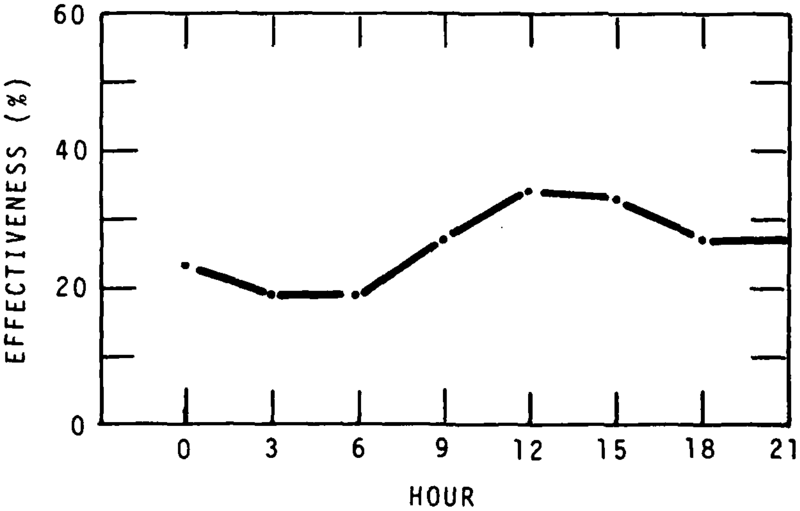


FIGURE 63. VAS EFFECTIVENESS FOR SEA RUNWAY 16/34

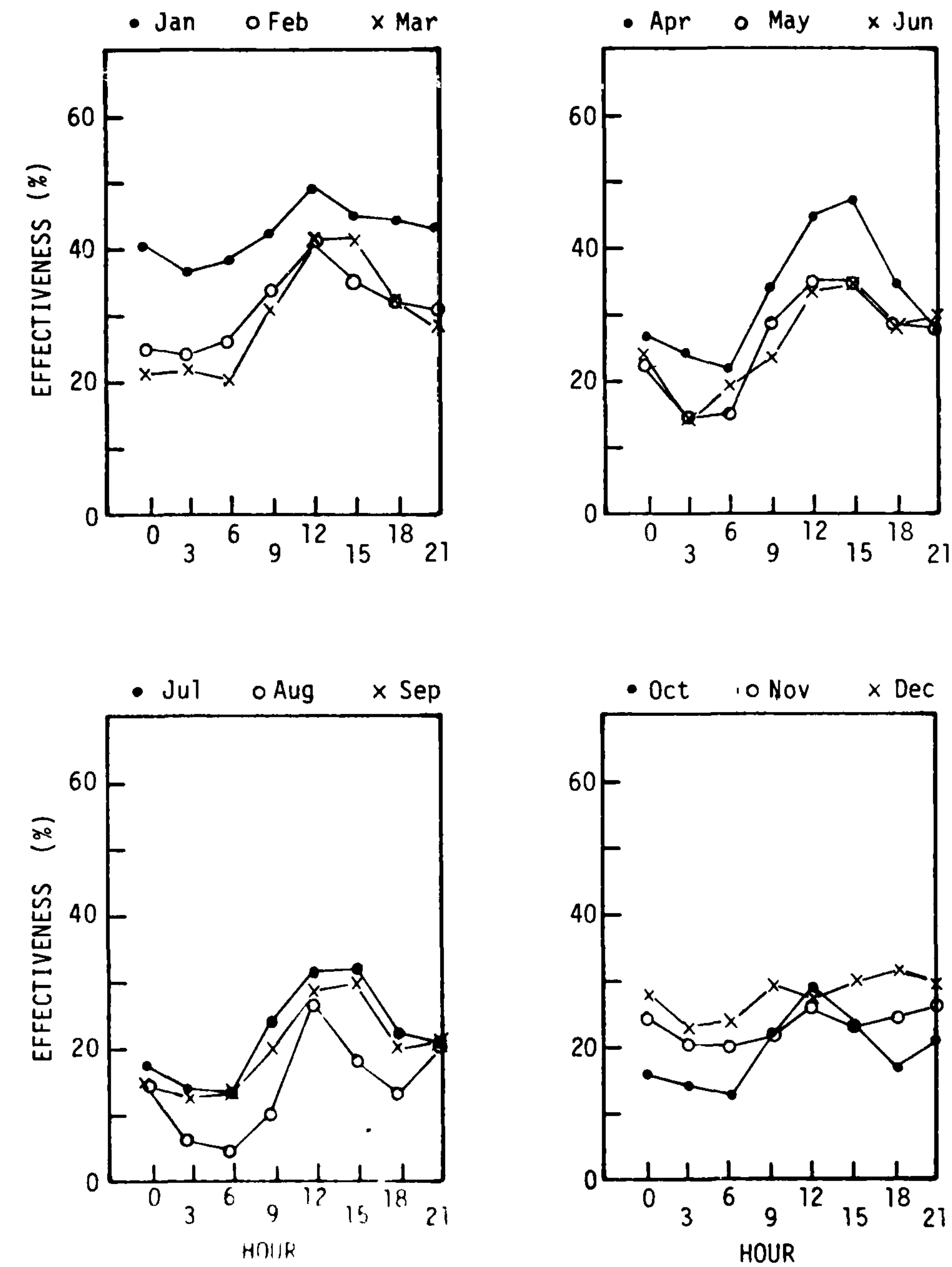


FIGURE [illegible]. [illegible] EFFECTIVENESS FOR SEA RUNWAY 16/34 (CONCLUDED)

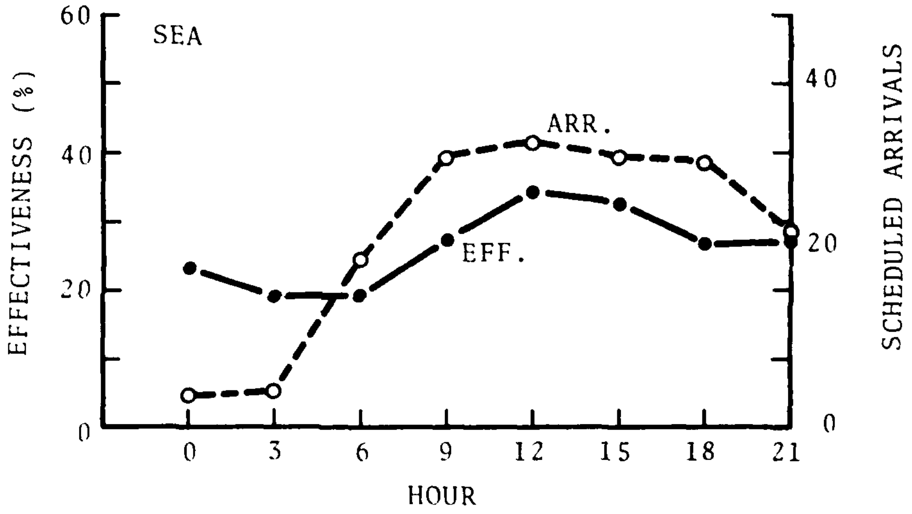


FIGURE 65. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR SEA

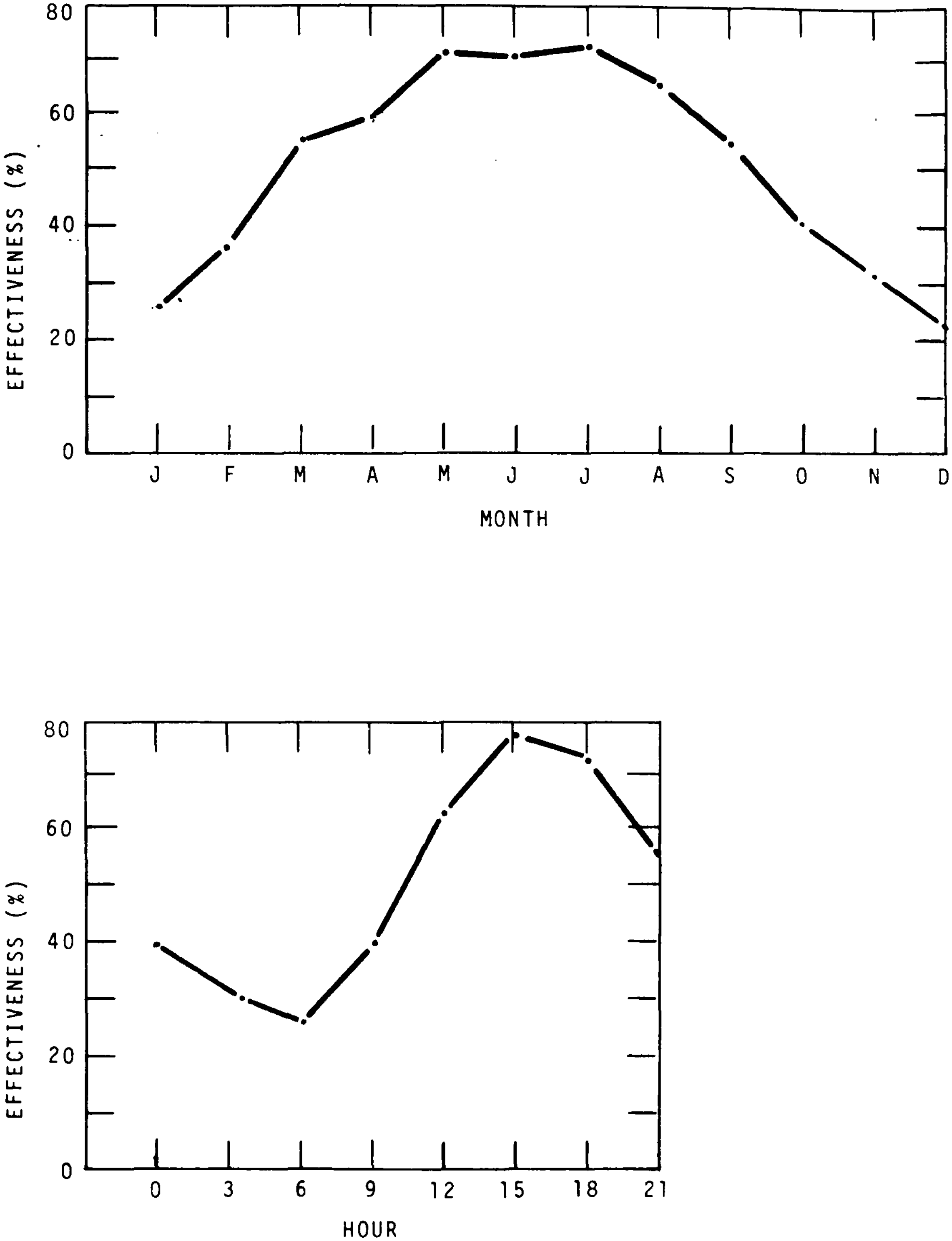


FIGURE 66. VAS EFFECTIVENESS FOR SFO RUNWAY 1/19

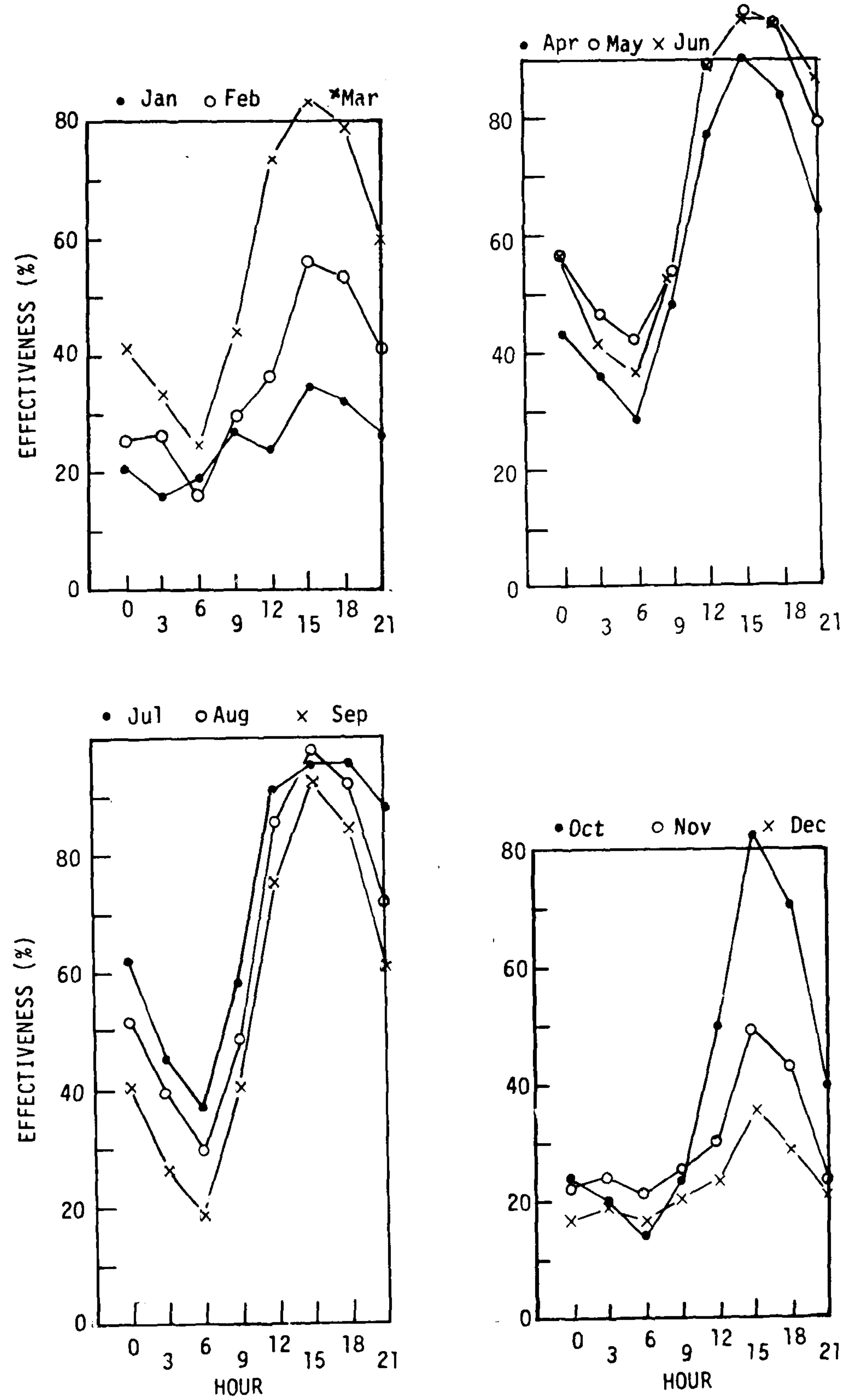


FIGURE 67. VAS EFFECTIVEN' FOR SFO RUNWAY 1/19 (CONCLUDED)

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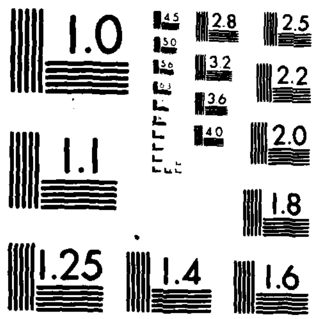

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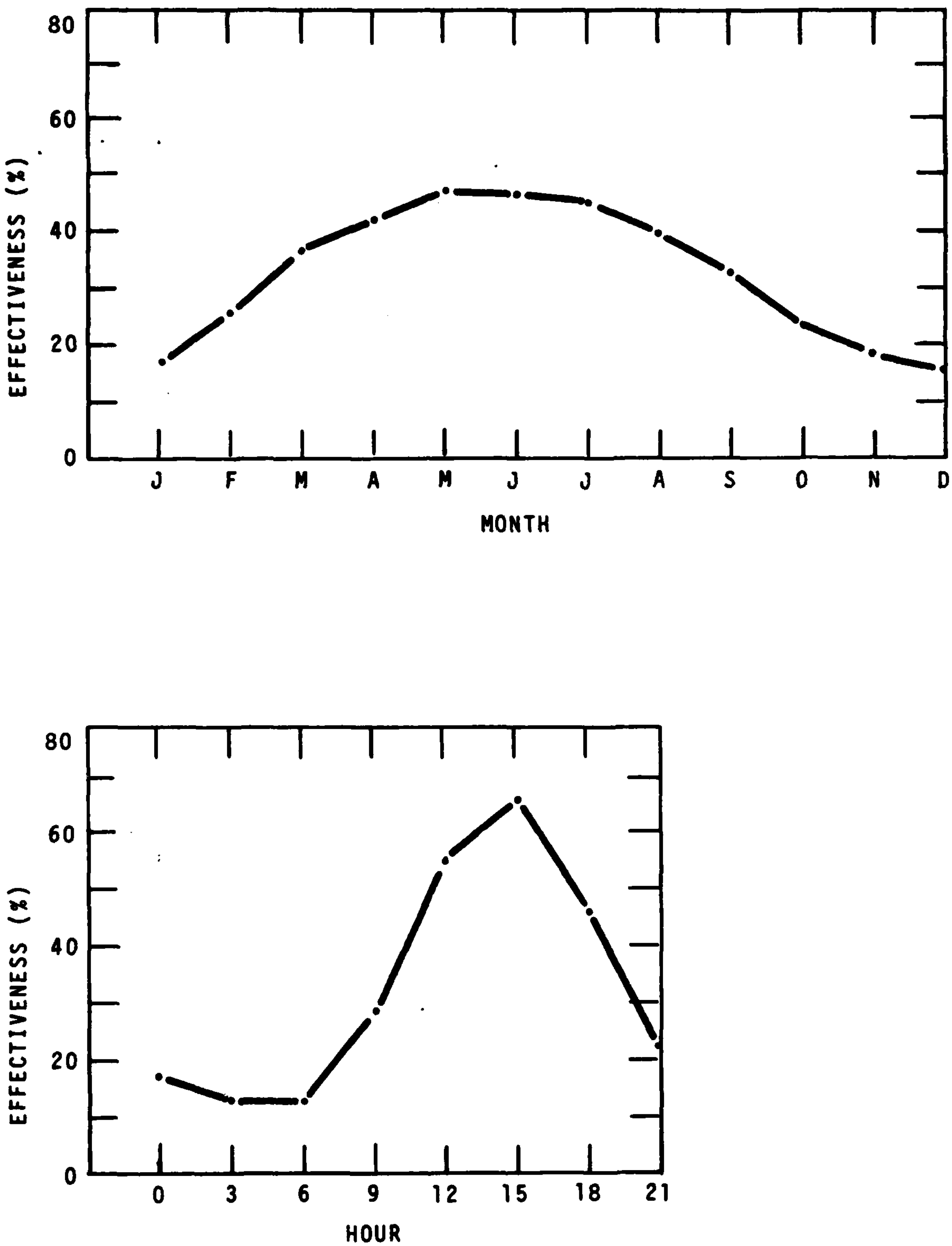


FIGURE 68. VAS EFFECTIVENESS FOR SFO RUNWAY 10/28

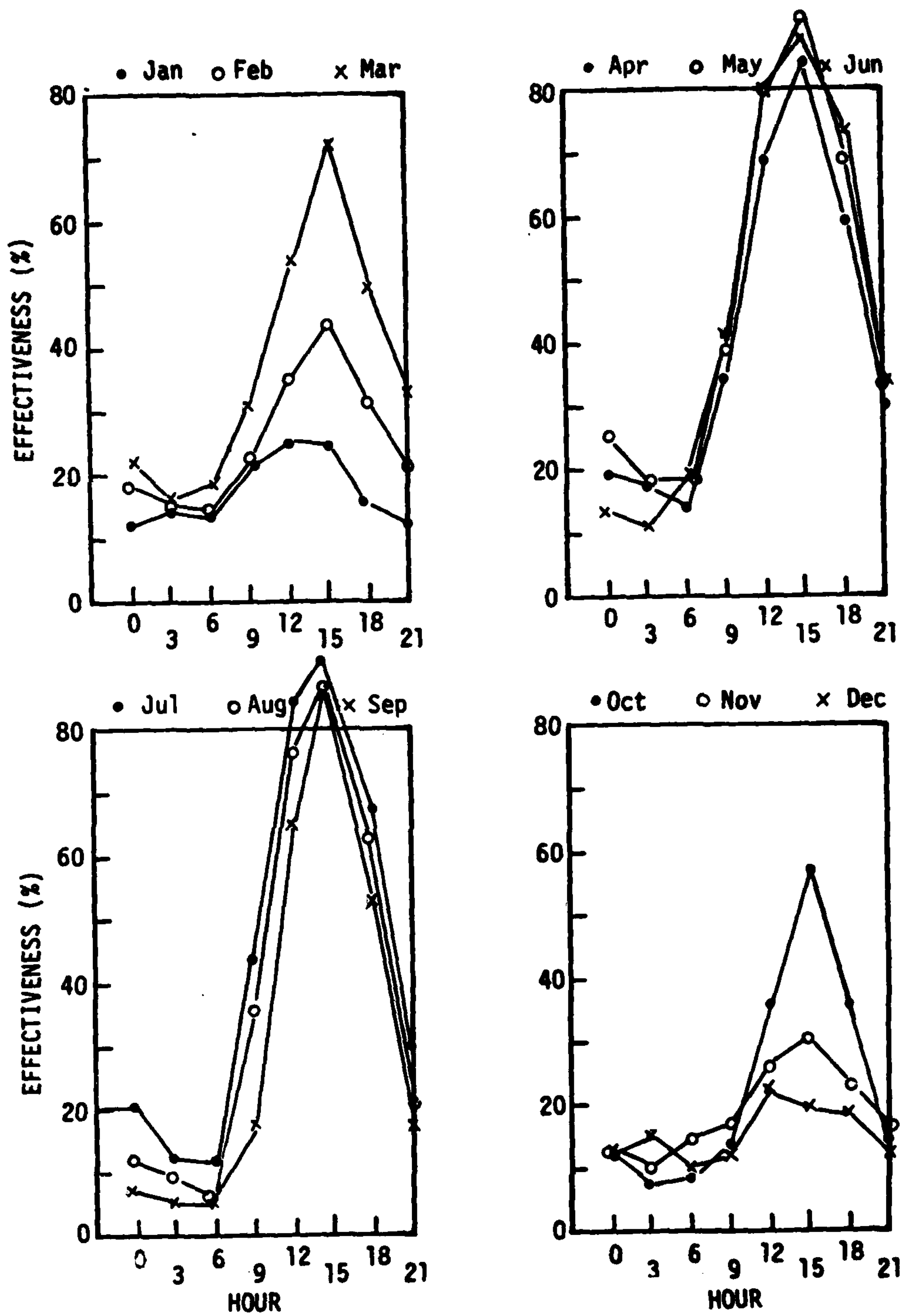


FIGURE 69. VAS EFFECTIVENESS FOR SFO RUNWAY 10/28 (CONCLUDED)

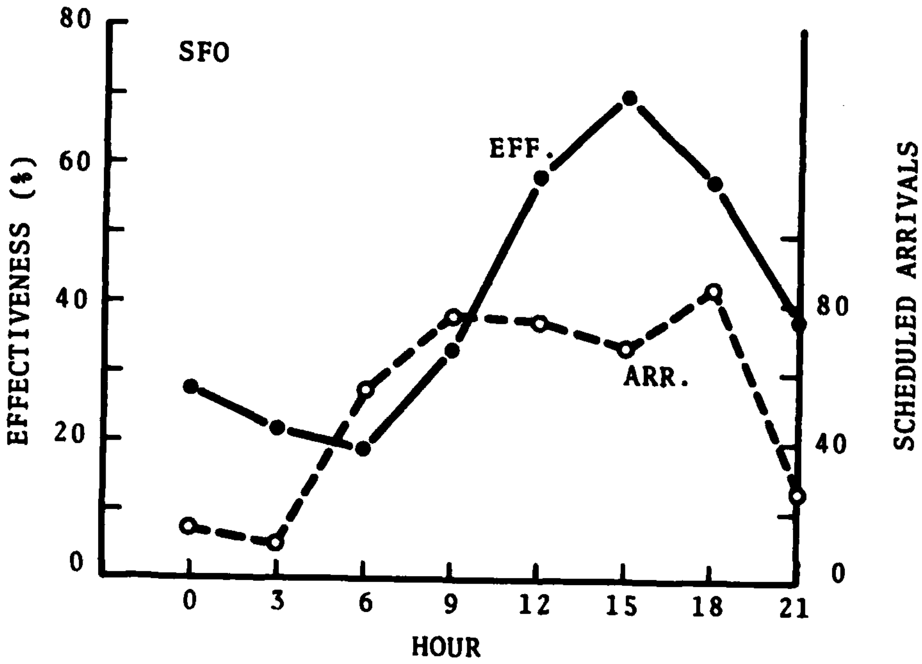
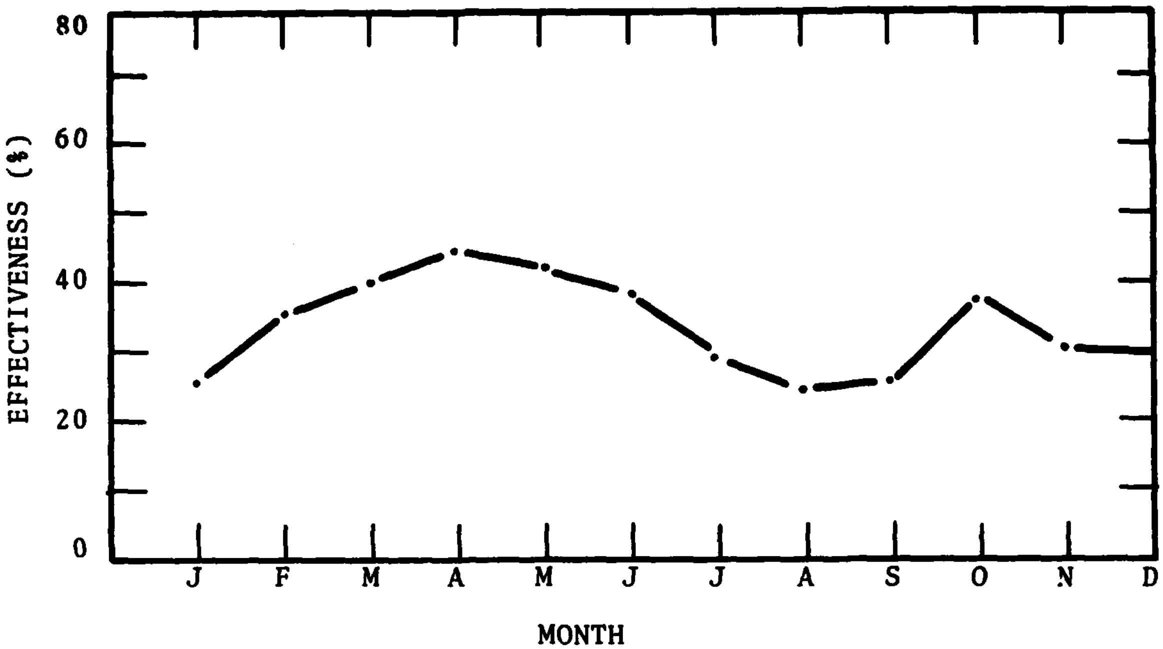


FIGURE 70. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR SFO



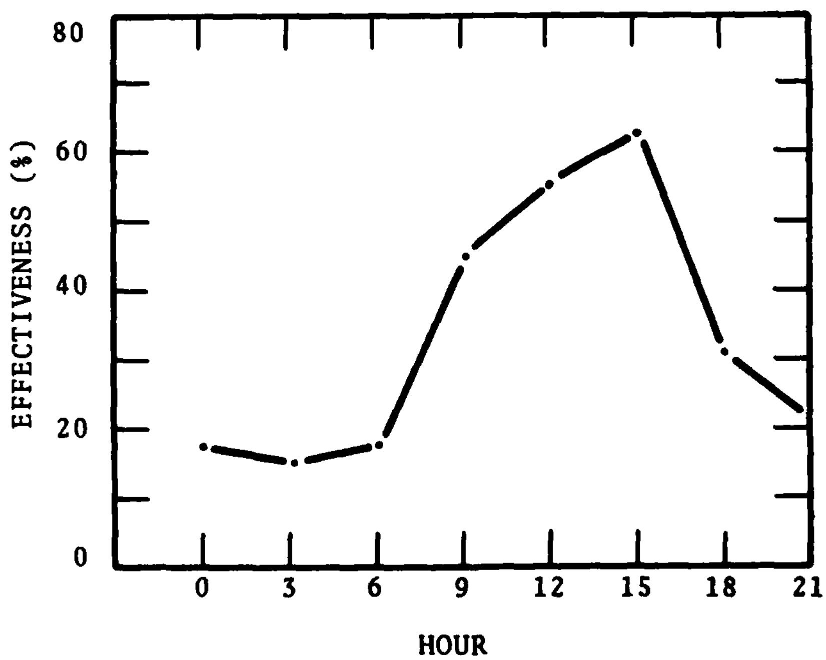


FIGURE 71. VAS EFFECTIVENESS FOR TPA RUNWAY 18/36

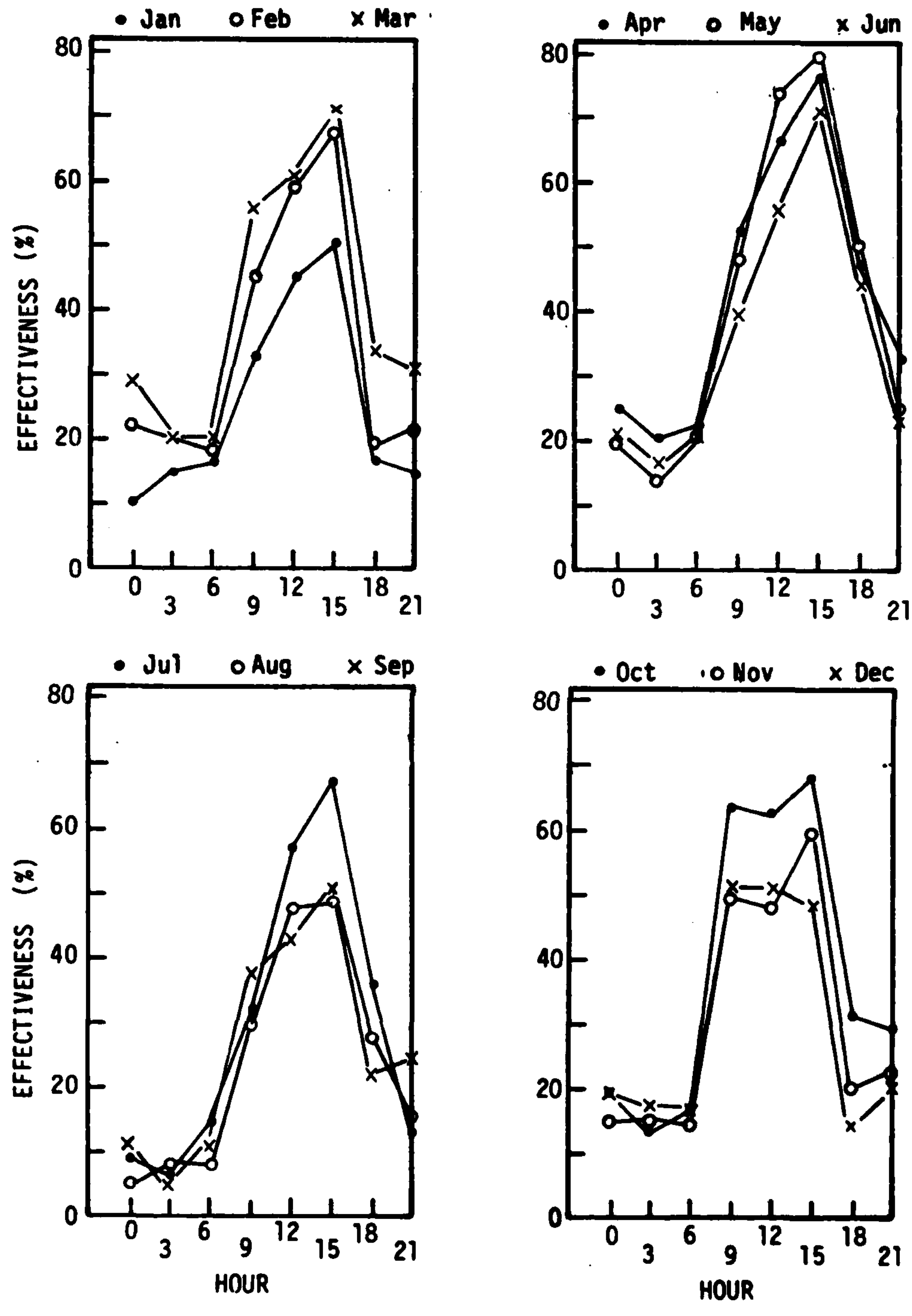


FIGURE 72. VAS EFFECTIVENESS FOR TPA RUNWAY 18/36
(CONCLUDED)

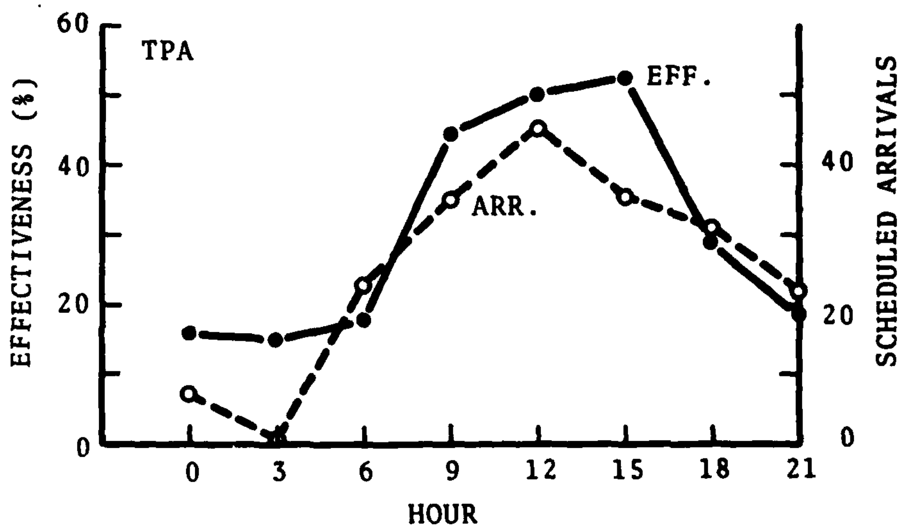
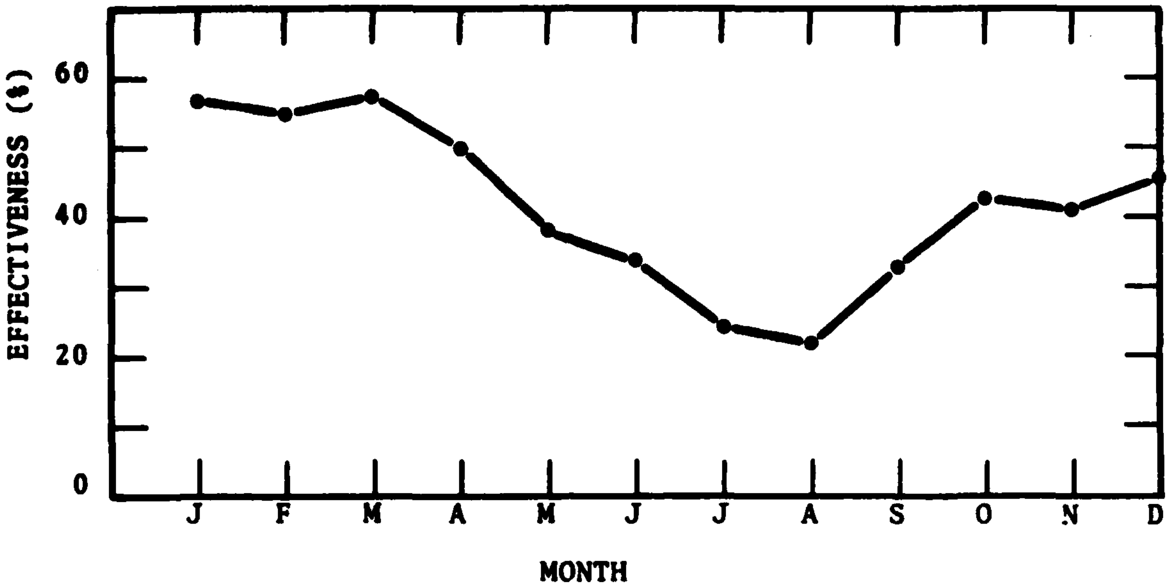


FIGURE 73. VAS EFFECTIVENESS AND ARRIVAL DEMAND VERSUS HOUR FOR TPA



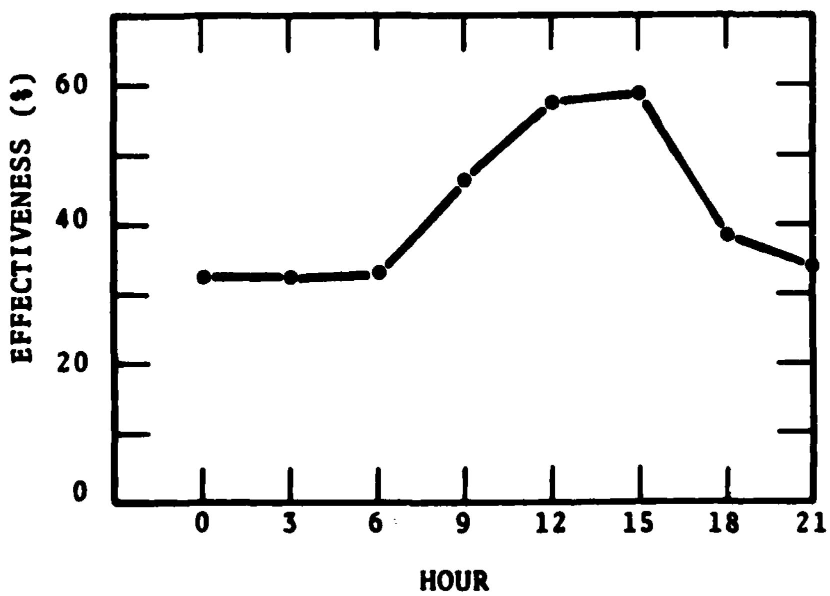


FIGURE 74. VAS EFFECTIVENESS FOR CLE RUNWAY 5/23

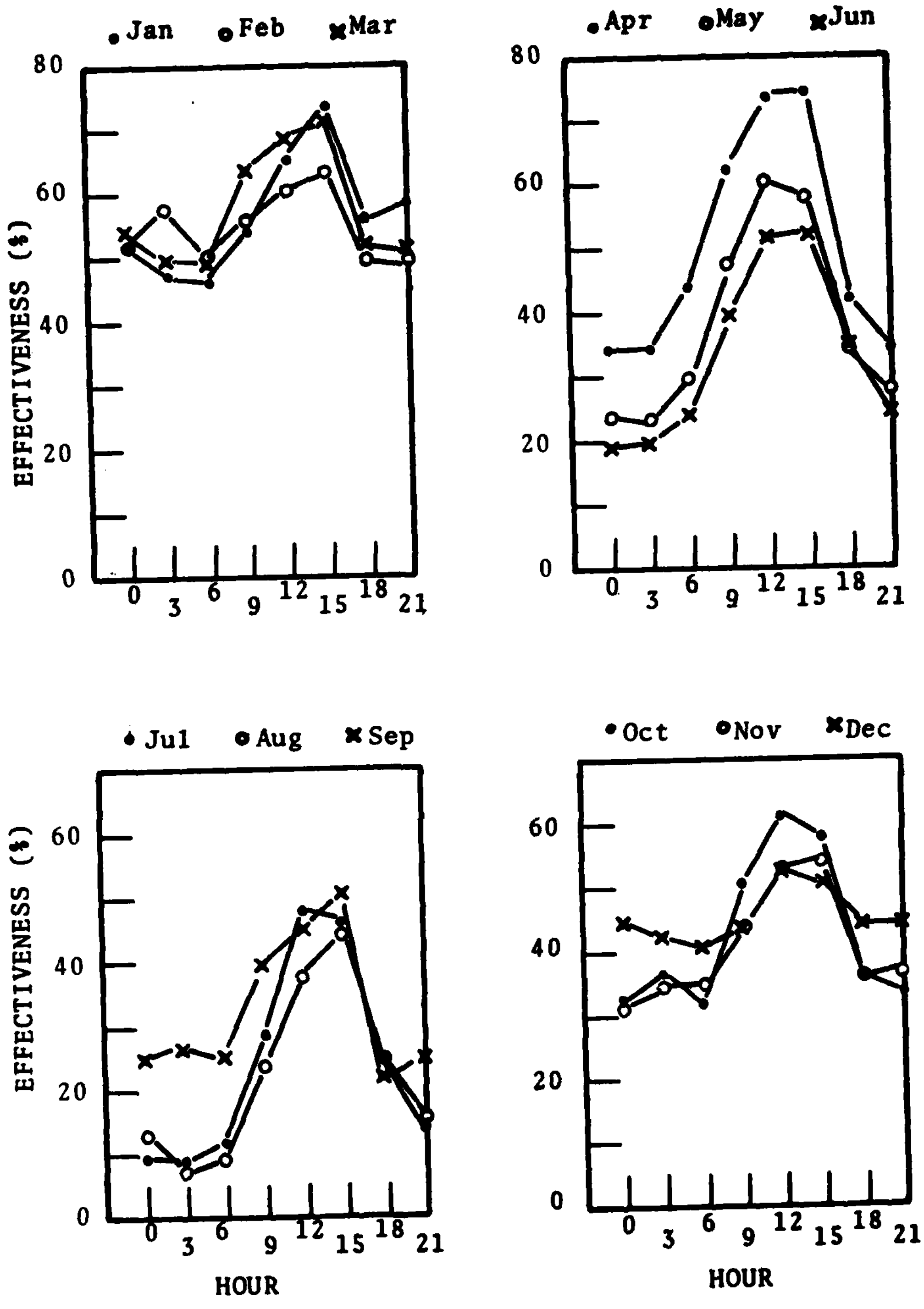
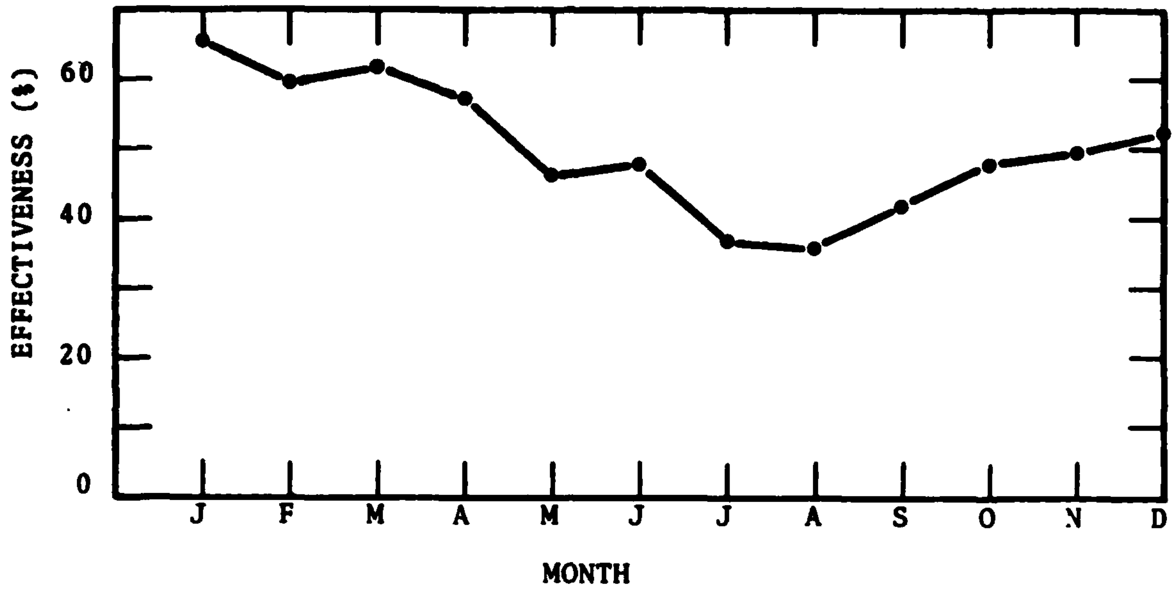


FIGURE 75. VAS EFFECTIVENESS FOR CLE RUNWAY 5/23 (CONCLUDED)



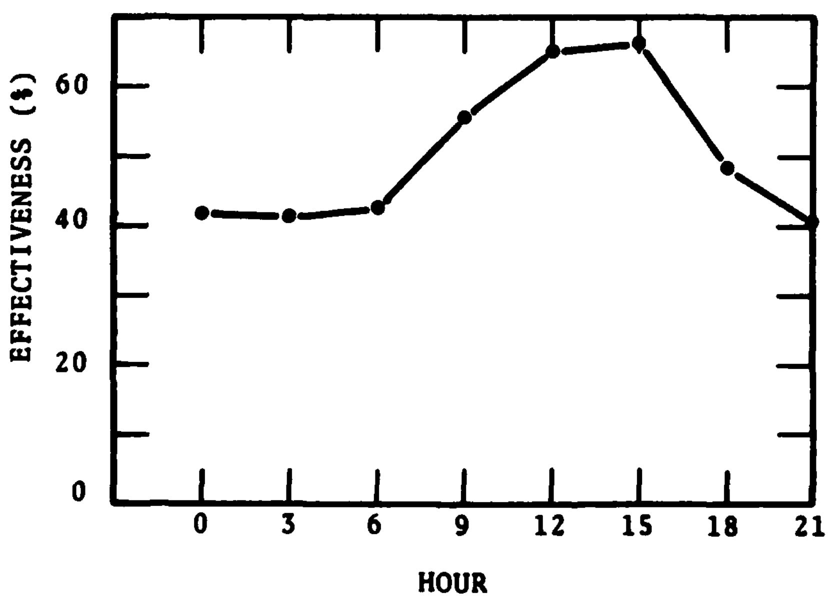


FIGURE 76. VAS EFFECTIVENESS FOR CLE RUNWAY 10/28

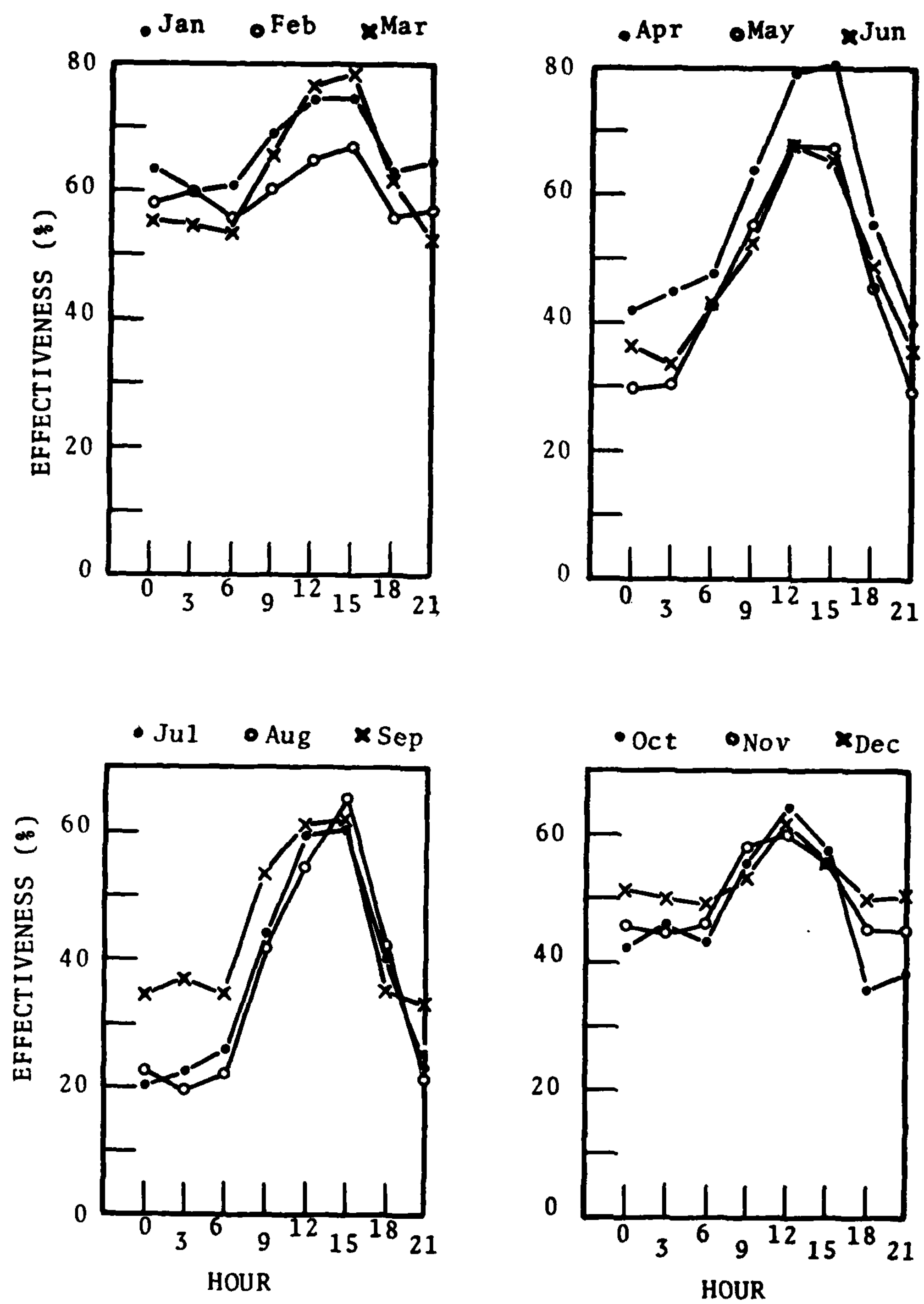
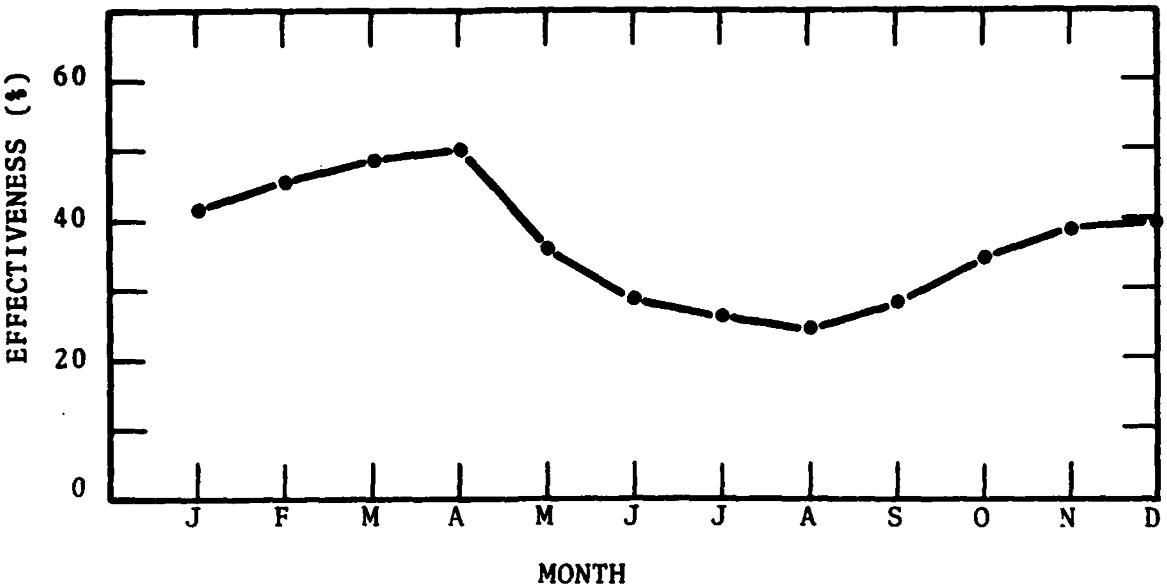


FIGURE 77. VAS EFFECTIVENESS FOR CLE RUNWAY 10/28 (CONCLUDED)



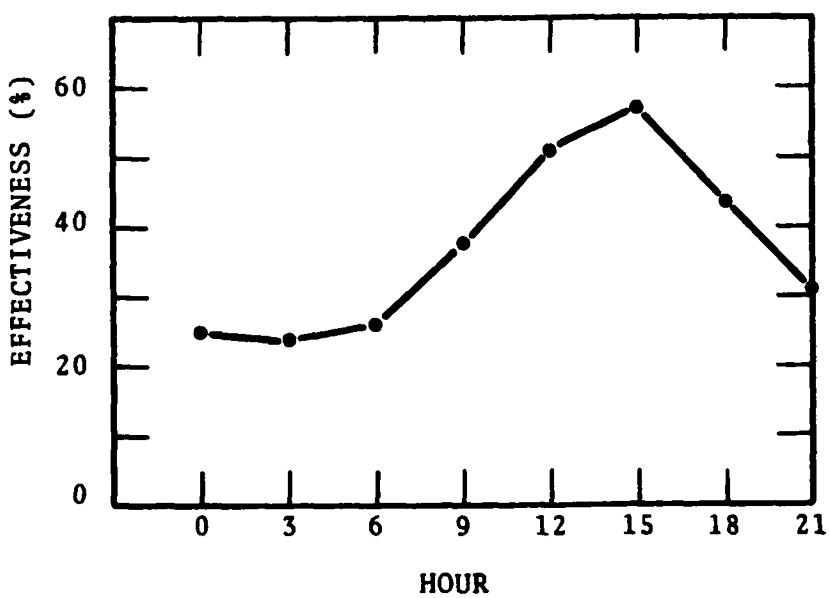


FIGURE 78. VAS EFFECTIVENESS FOR EWR RUNWAY 4/22

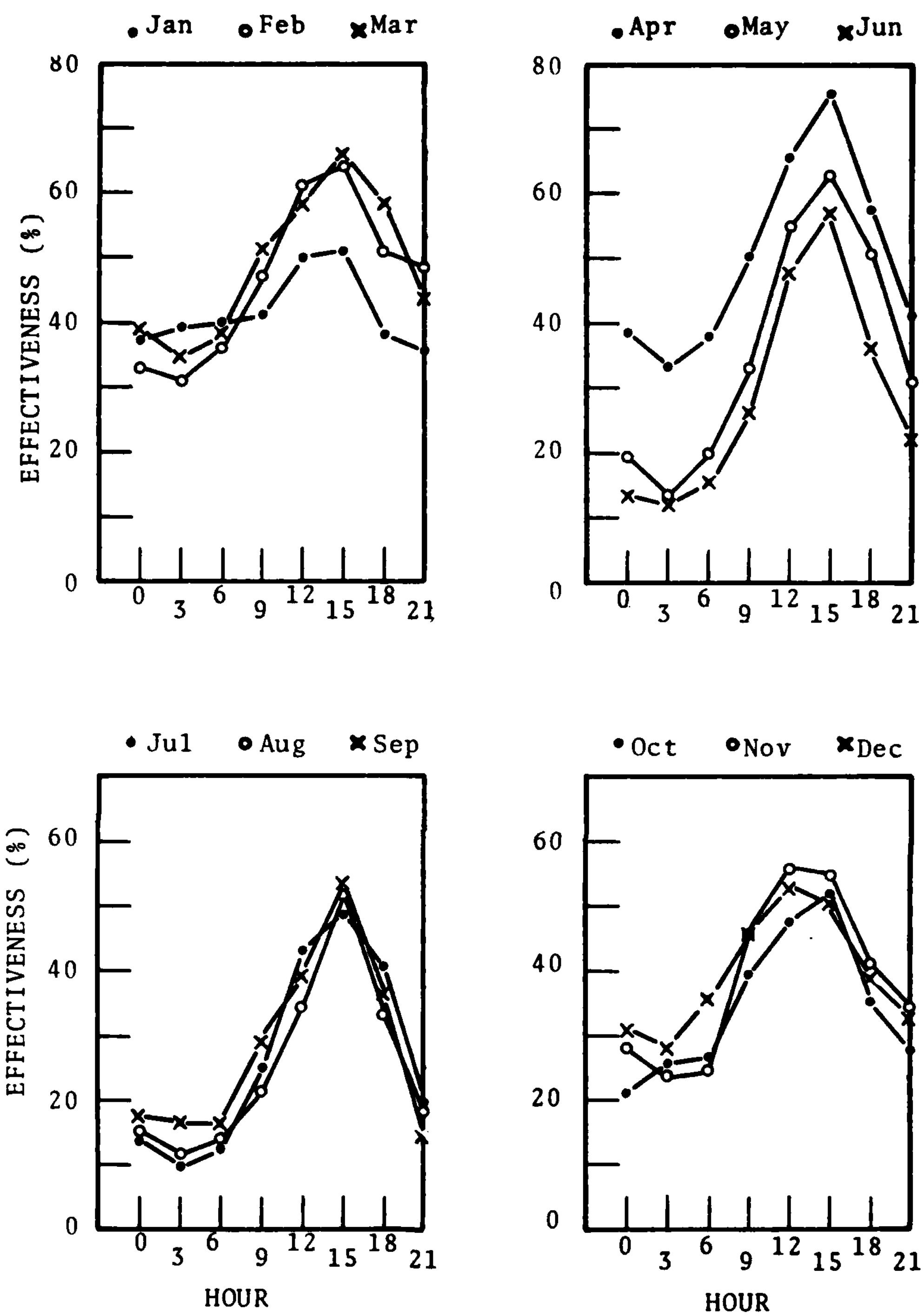
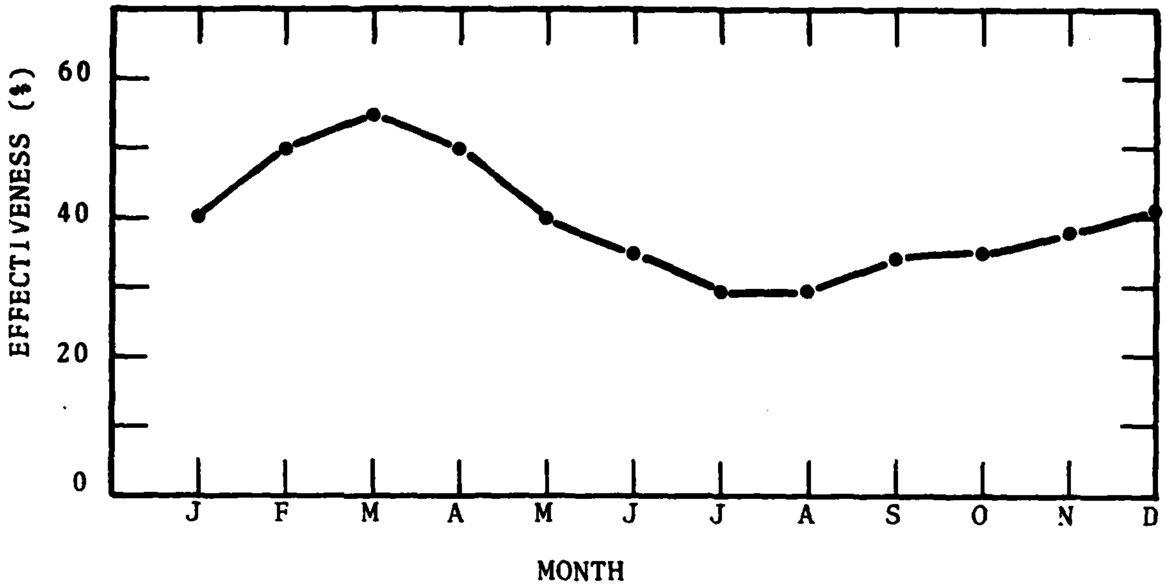


FIGURE 79. VAS EFFECTIVENESS FOR EWR RUNWAY 4/22 (CONCLUDED)



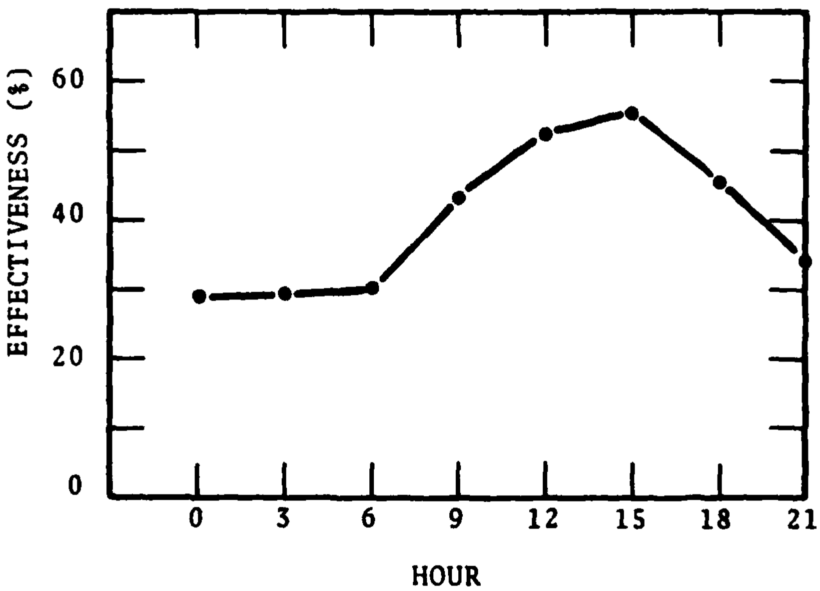


FIGURE 80. VAS EFFECTIVENESS FOR PHL RUNWAY 9/27

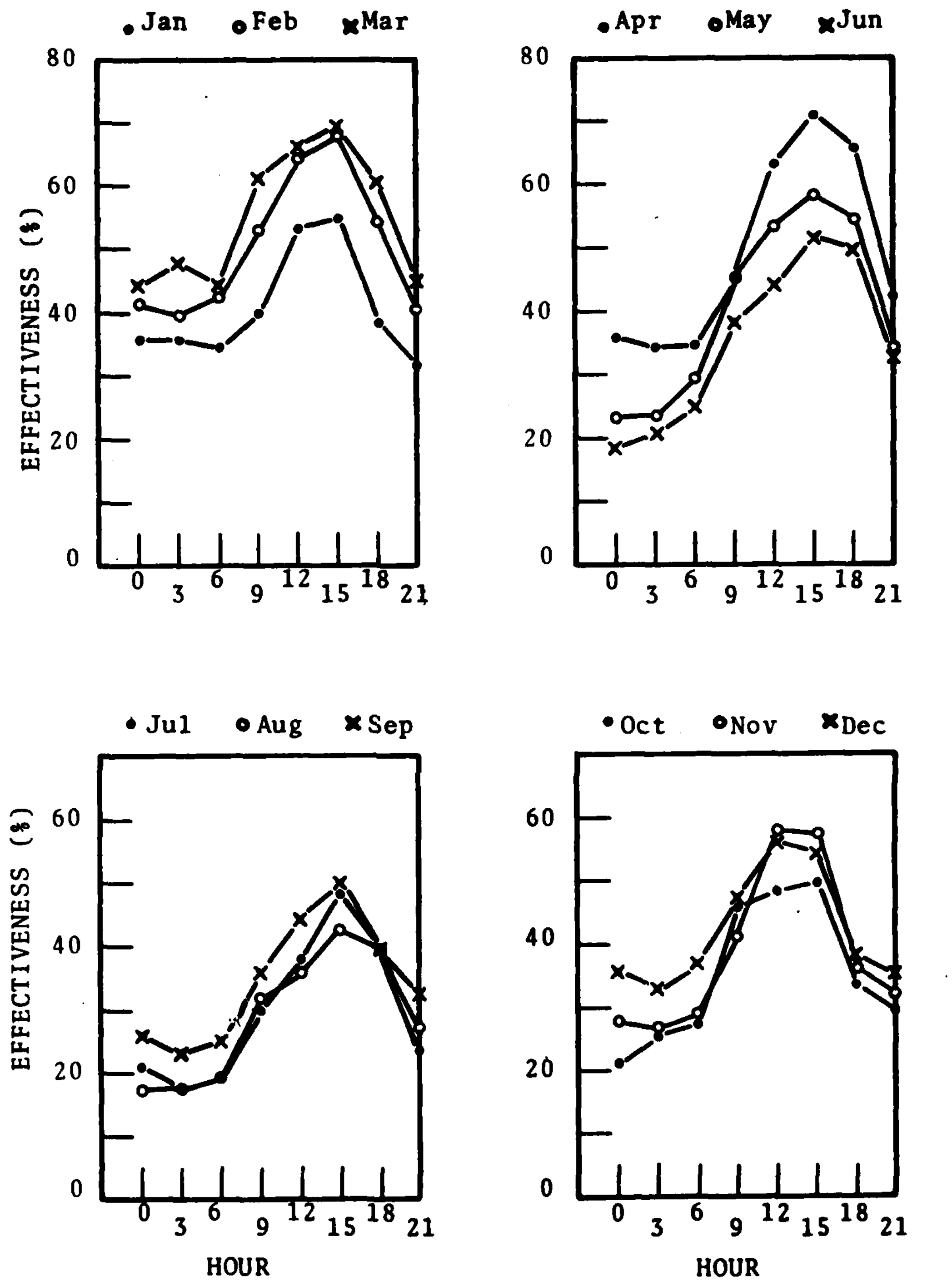


FIGURE 81. VAS EFFECTIVENESS FOR PHL RUNWAY 9/27 (CONCLUDED)

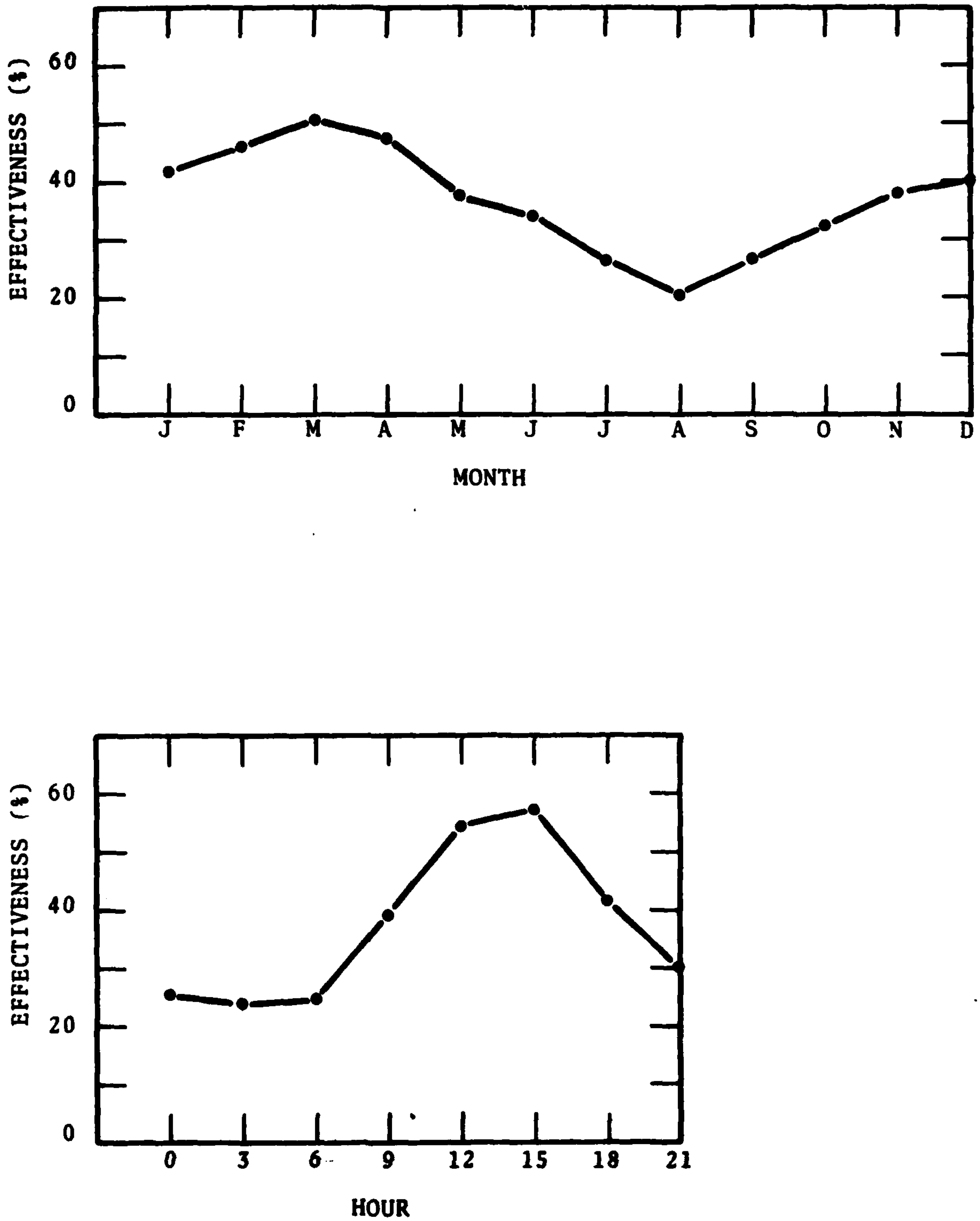


FIGURE 82. VAS EFFECTIVENESS FOR PIT RUNWAY 10/28

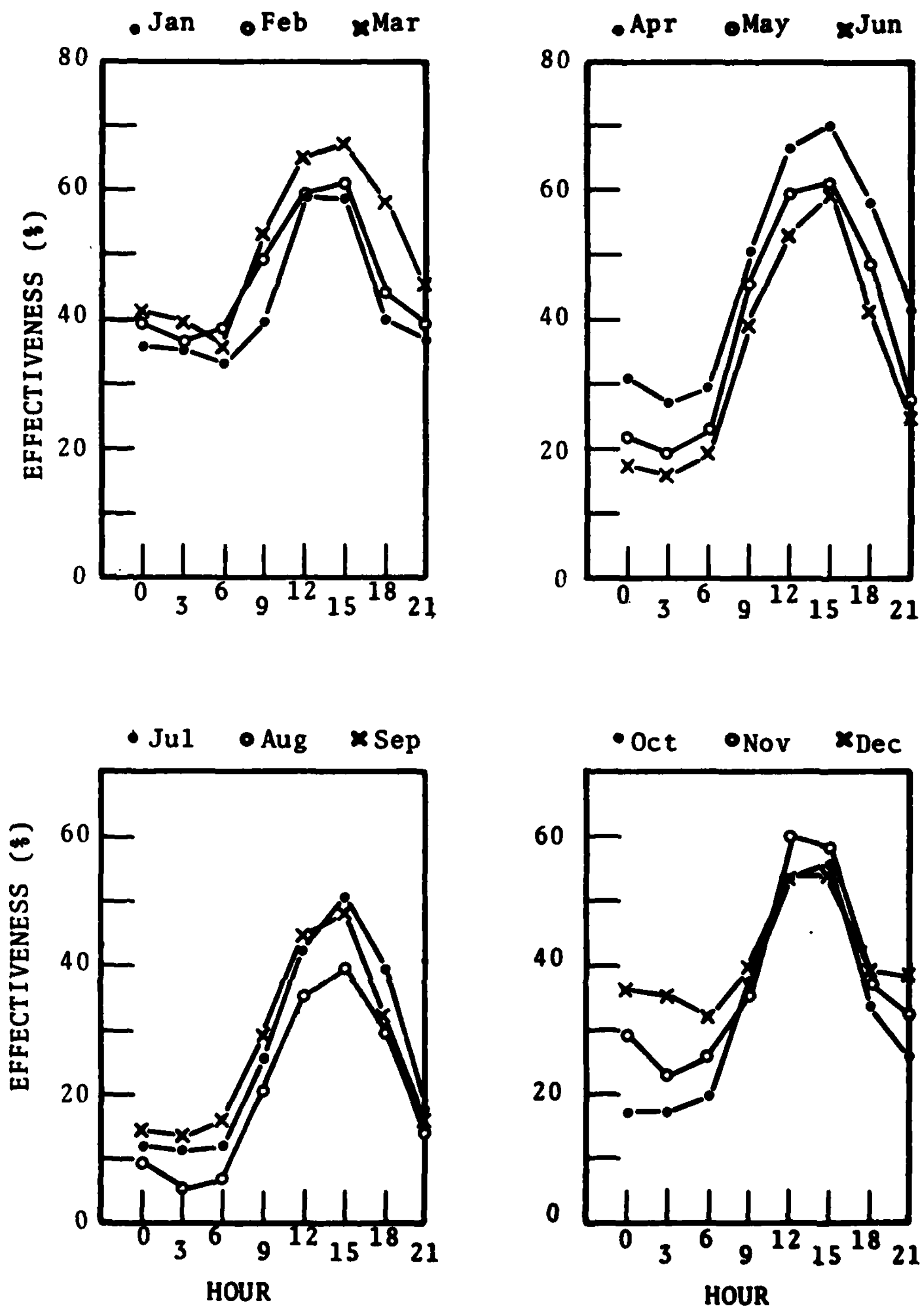


FIGURE 83. VAS EFFECTIVENESS FOR PIT RUNWAY 10/28 (CONCLUDED)

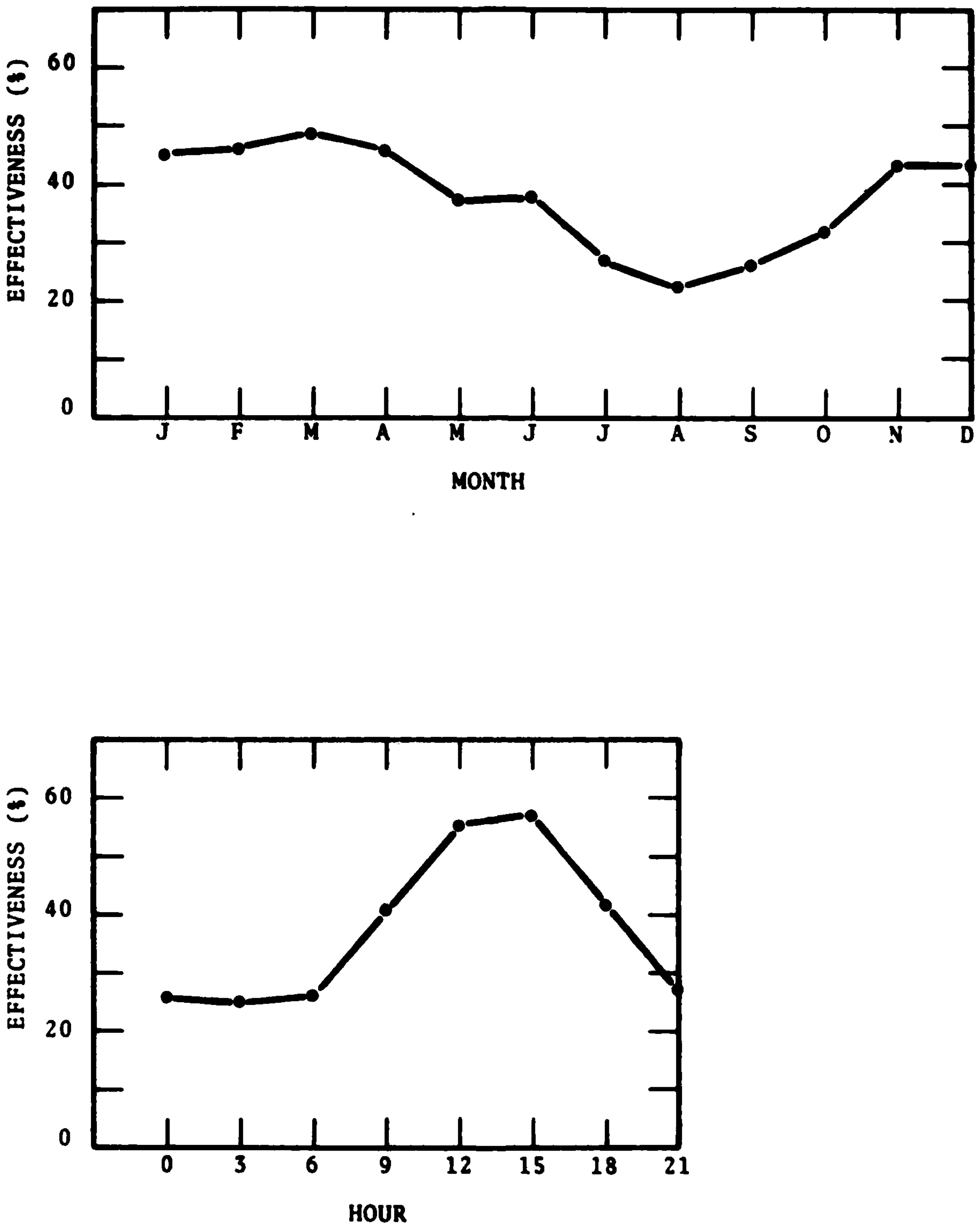


FIGURE 84. VAS EFFECTIVENESS FOR PIT RUNWAY 14/32

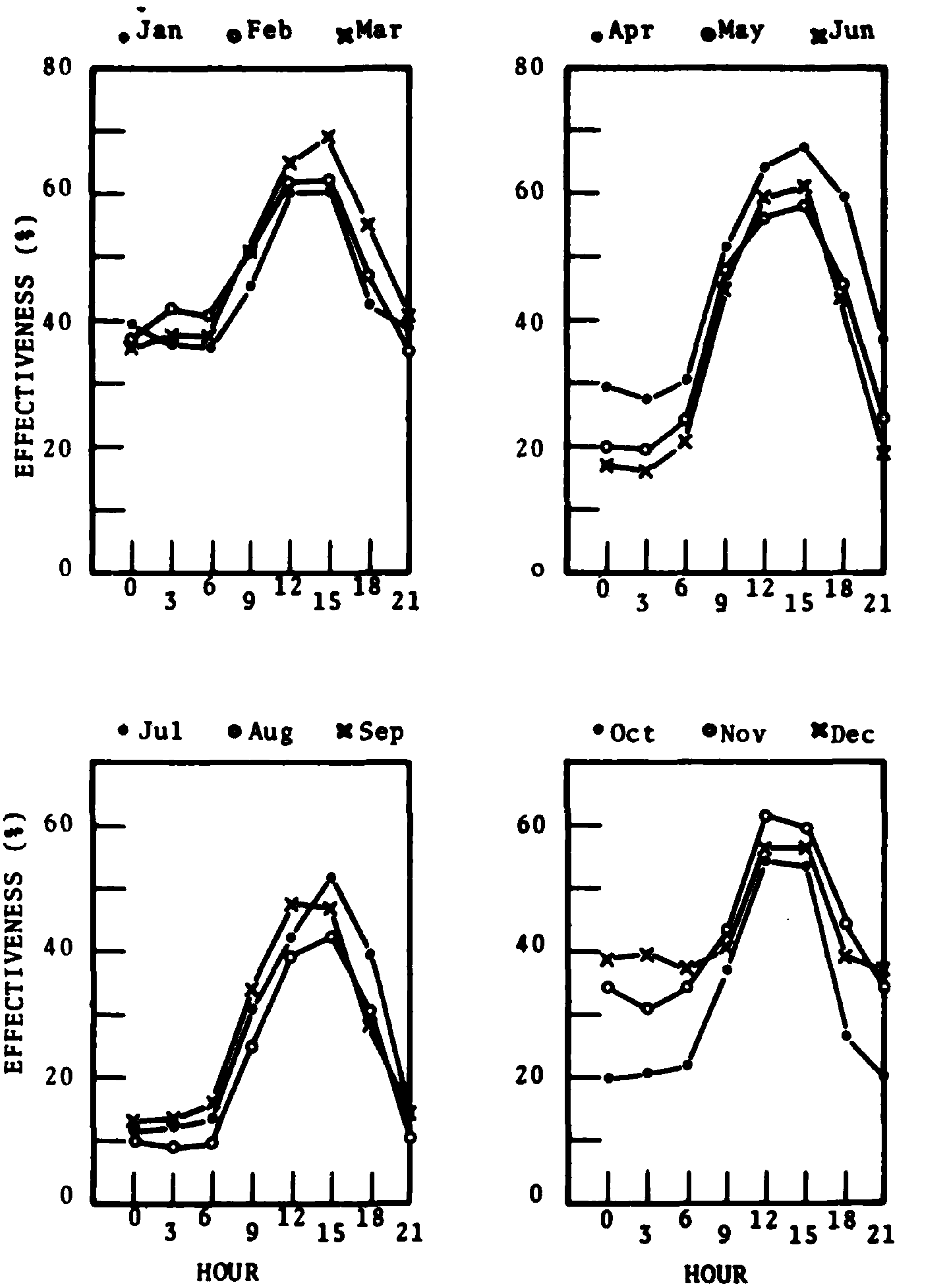


FIGURE 85. VAS EFFECTIVENESS FOR PIT RUNWAY 14/32 (CONCLUDED)

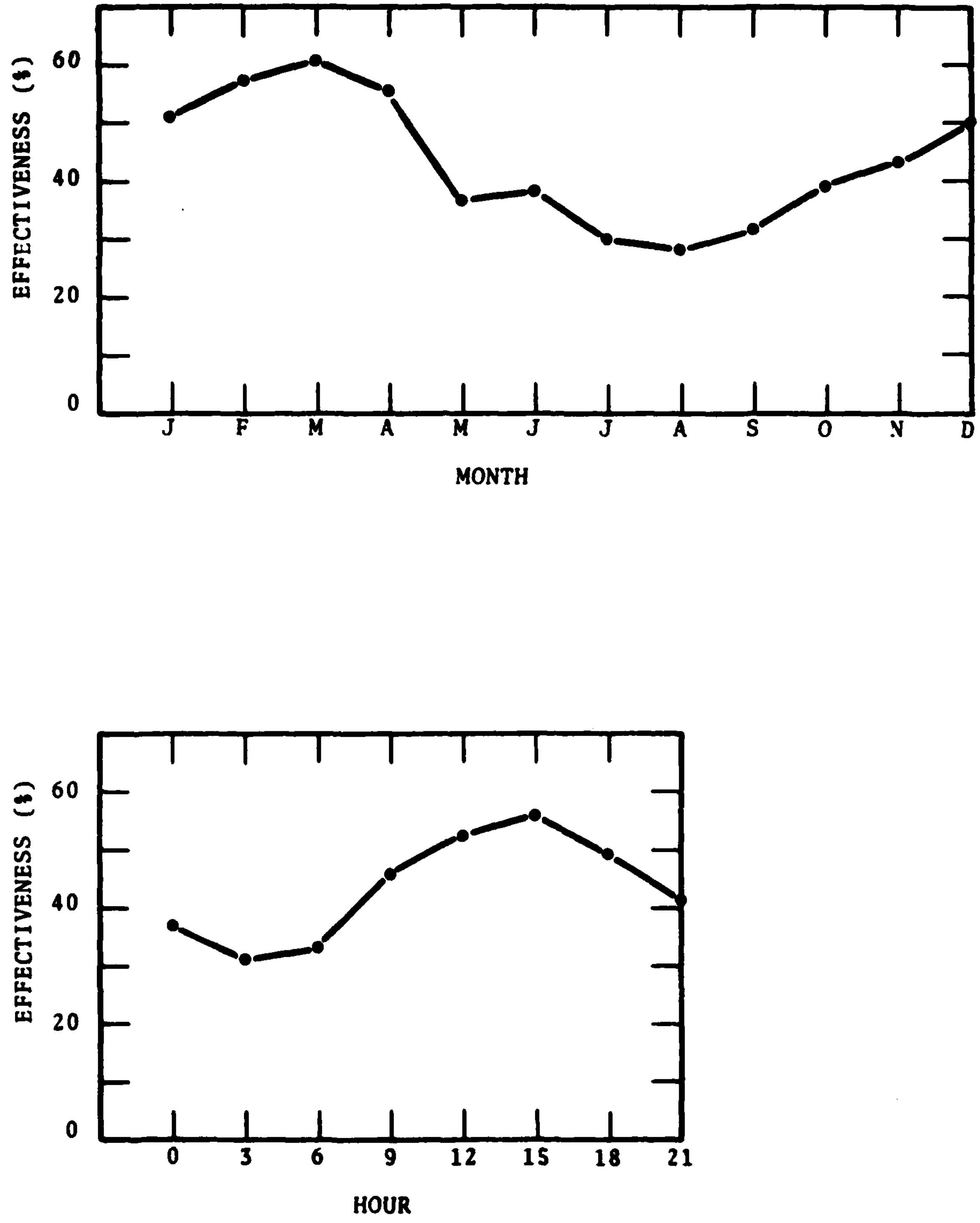


FIGURE 86. VAS EFFECTIVENESS FOR STL RUNWAY 6/24

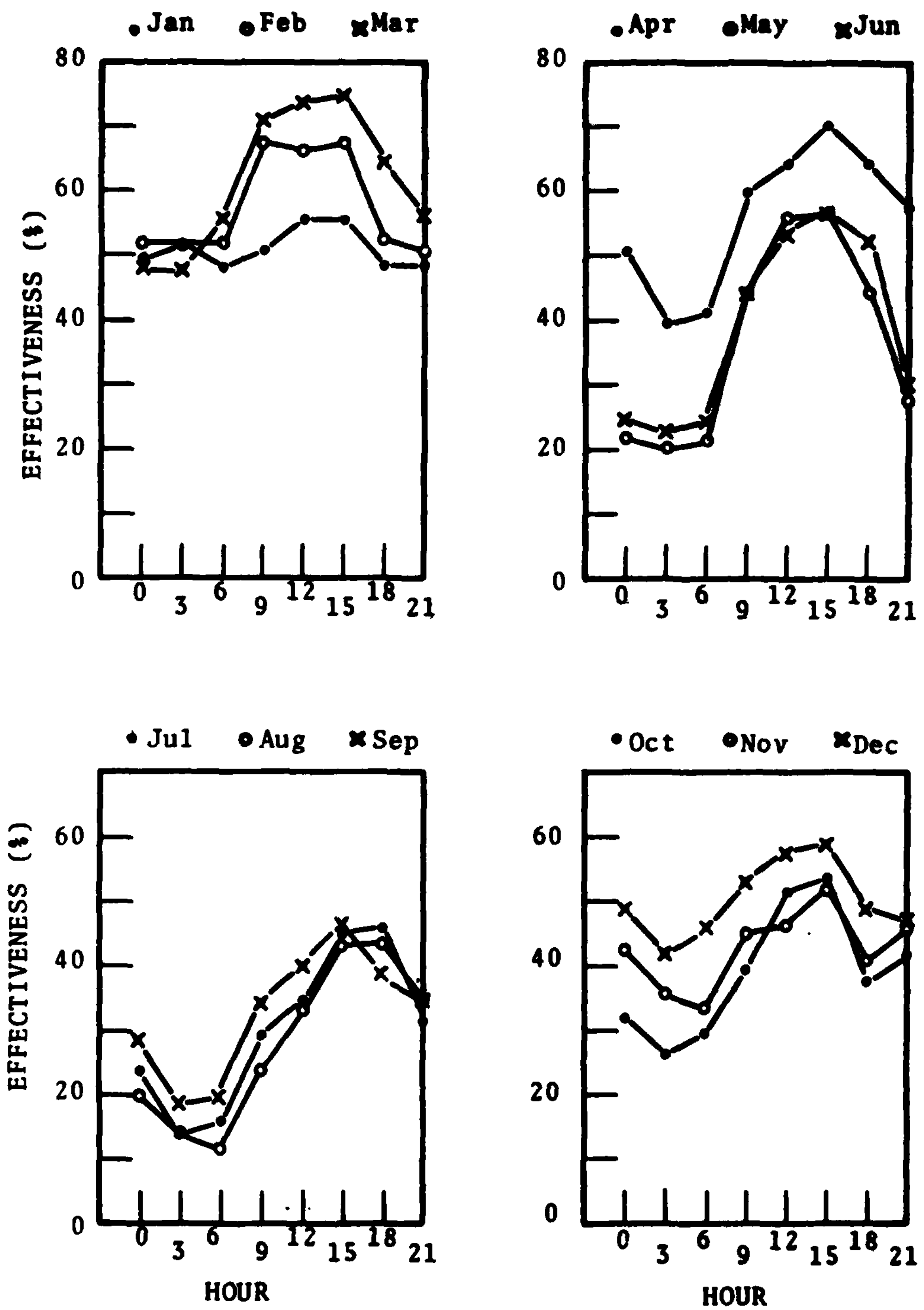
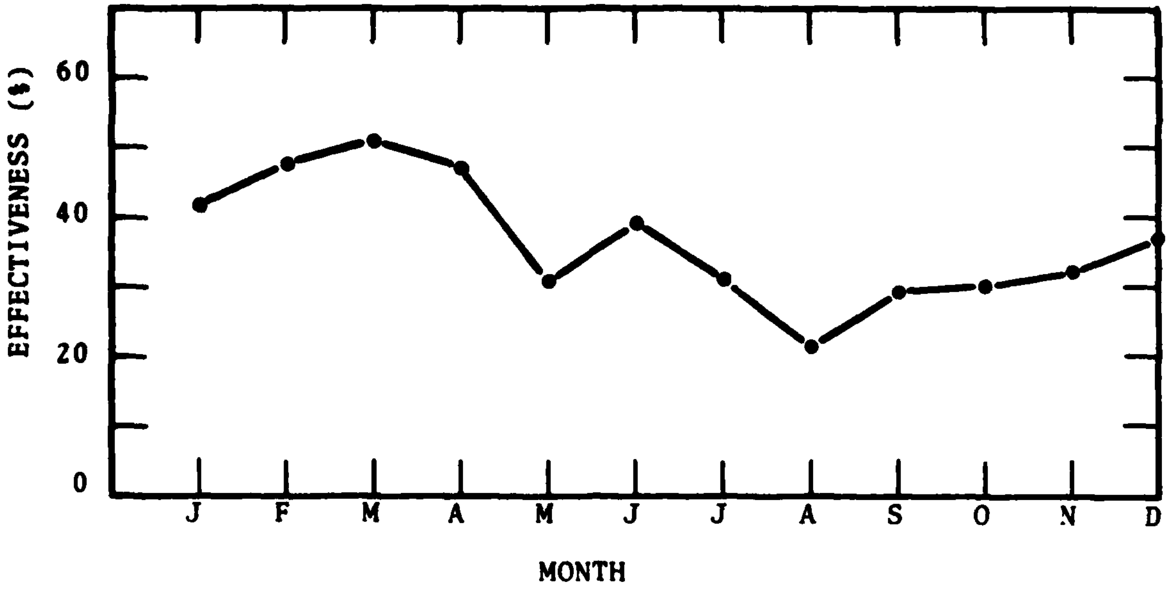


FIGURE 87. VAS EFFECTIVENESS FOR STL RUNWAY 6/24 (CONCLUDED)



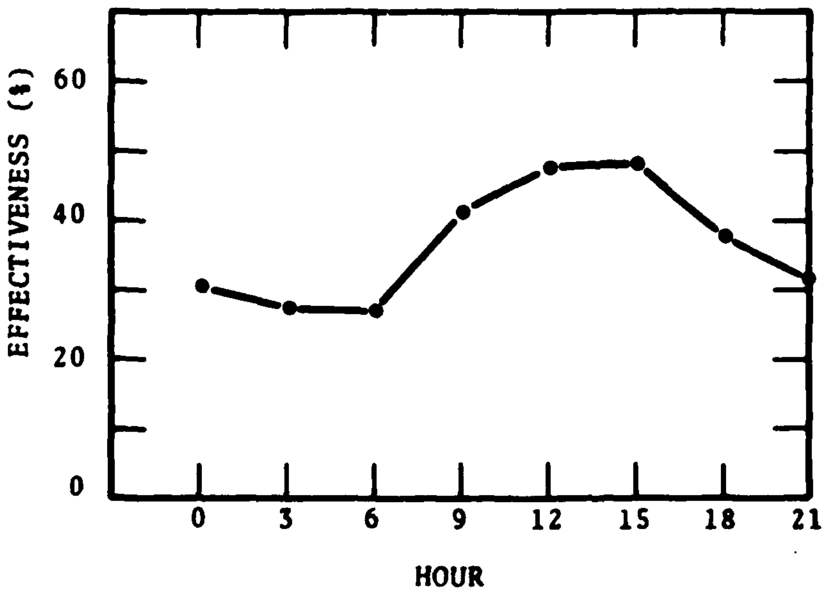


FIGURE 88. VAS EFFECTIVENESS FOR STL RUNWAY 12/30

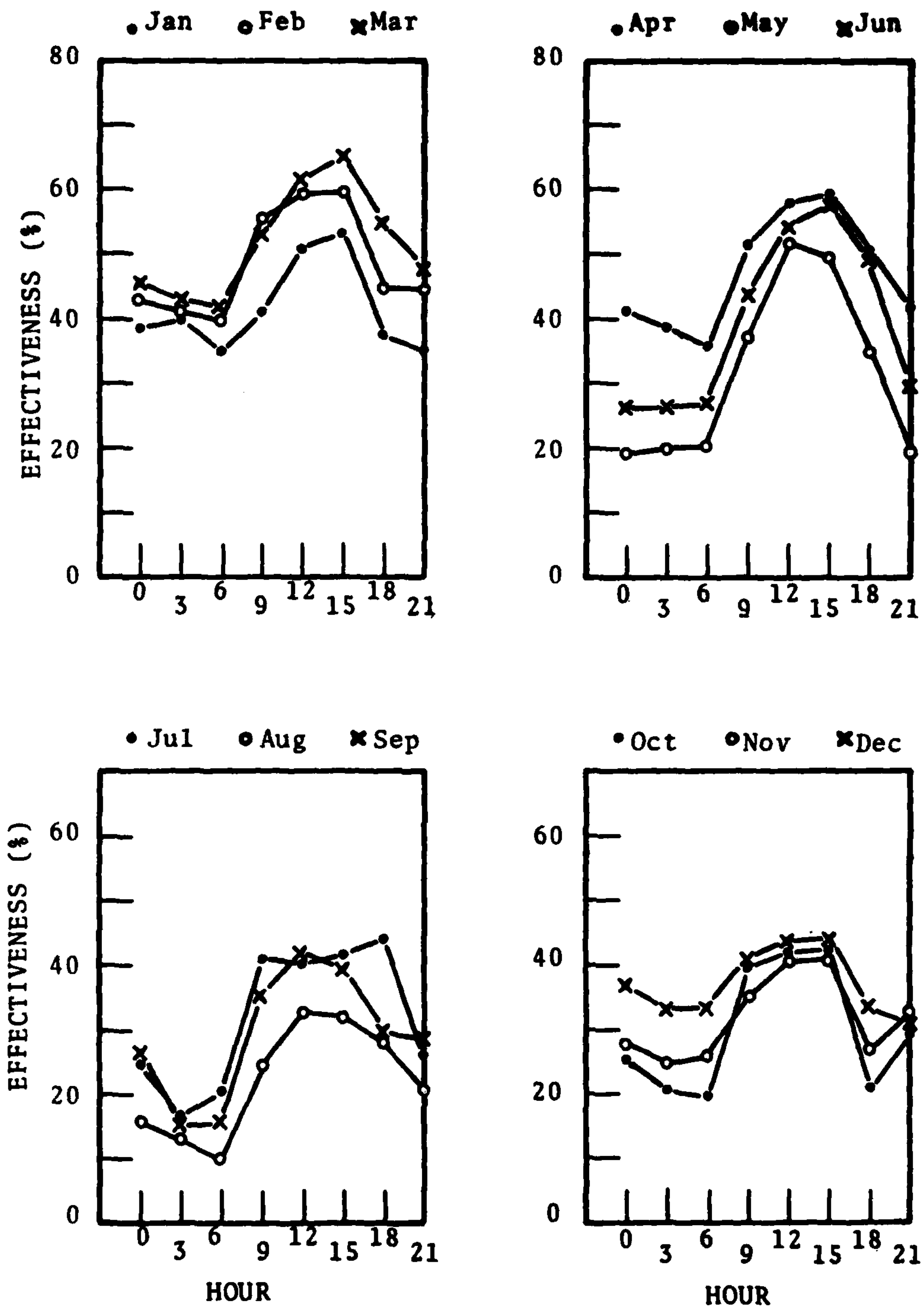


FIGURE 89. VAS EFFECTIVENESS FOR STL RUNWAY 12/30 (CONCLUDED)

4. COMMENTS AND SUMMARY

4.1 OTHER GUARD-BAND SIZES

The effectiveness values presented in Section 3 are predicated on the use of a 2-knot guard band inscribed about the VAS ellipse (see Figure 2). Without a guard band, the VAS could change state (from green to red, from red to green) often. If an air traffic controller could respond to such changes and the attendant effects on the interarrival traffic flow, the VAS could be operated at its maximum efficiency. However, changes in state (green light, red light), particularly rapid changes, decrease the utility of the VAS; hysteresis has been introduced to minimize the number of transitions in state (Section 2.2).

Figure 90 gives a scale factor to be used for various guard-band sizes. The curve is obtained by using the wind data for ORD. For a 2-knot guard band, the scale factor is 1.0. For no guard band, the effectiveness scales of Figures 3 through 89 must be multiplied by a scale factor of approximately 1.34 (note that effectiveness values in excess of 100 percent are interpreted as being equal to 100 percent). For a guard-band size of 8 knots, the effectiveness values must be multiplied by the scale factor of approximately 0.32. In other words, using an 8-knot guard band the effectiveness of the VAS decreases by a factor about one-third, but the number of changes of state (from red to green, from green to red) will decrease by a greater amount. (Volume II of this report will address this situation in great detail for ORD.)

The scale-factor curve has been obtained by calculating the effectiveness curves (for ORD) using various guard-band sizes. The scale factors for each datum point are extracted, and the average scale factor for each guard-band size is then found for the curve in Figure 90.

The scale-factor curve is really valid only for ORD. Applying the curve to the data for other airports, while not strictly

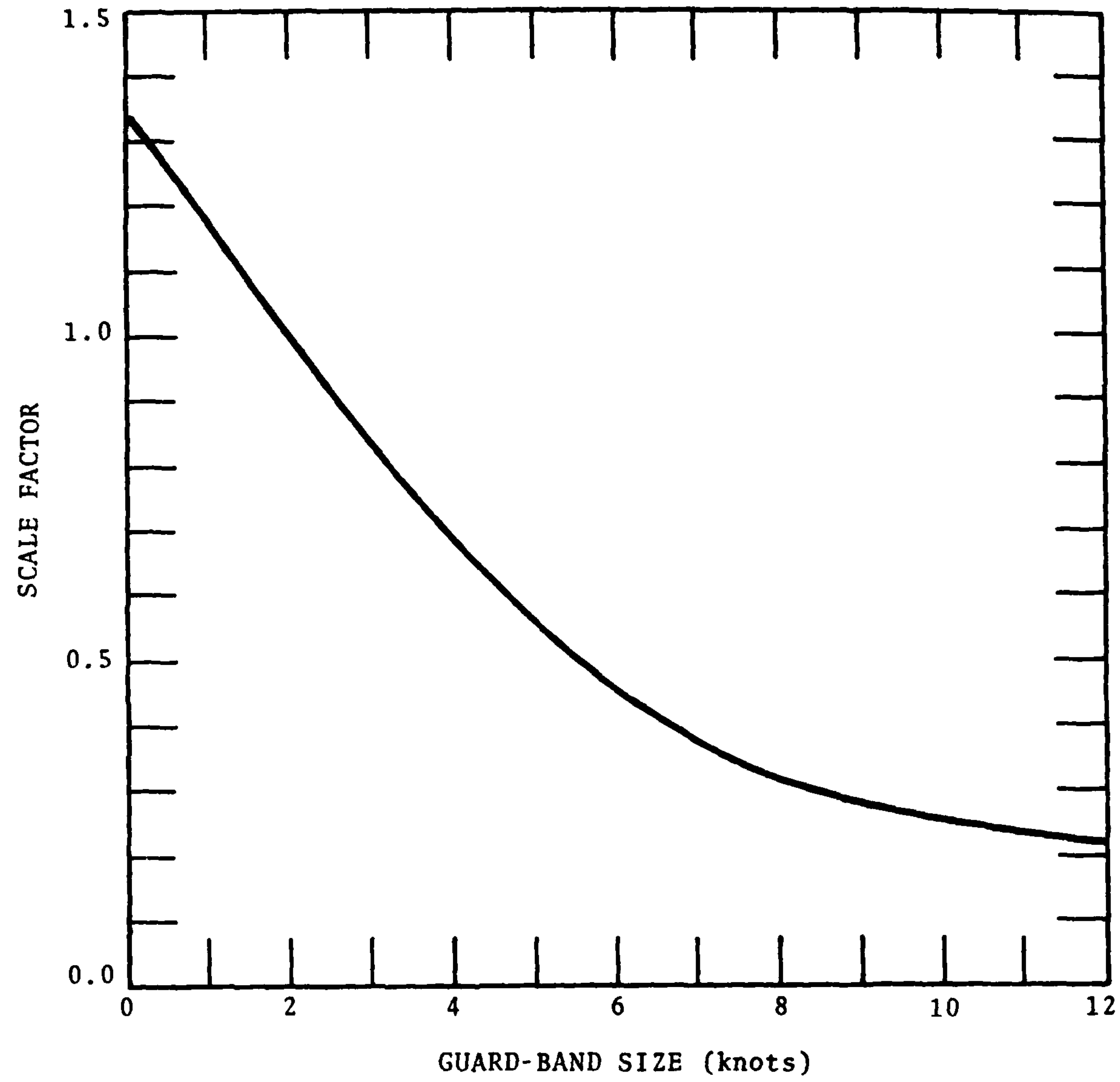


FIGURE 90. SCALE FACTOR FOR VARIOUS GUARD-BAND SIZES

valid, will give a first-order estimate of the effect of varying the guard-band size.

4.2 ENHANCEMENTS

The VAS uses just the 1-minute-averaged wind velocity compared with an elliptical wind criterion to determine when interarrival separations can be set at a uniform 3 nautical miles for all aircraft. Although the effectiveness is sometimes great, there are times and airports (e.g., LAX) where the VAS is of limited utility.

Research is underway to identify other quantities which may increase the effectiveness; e.g., atmospheric stability and turbulence. It is suspected that whenever the turbulence level is above a critical (albeit undetermined) value, the vortices will decay so rapidly that 3 nautical miles will be safe regardless of the VAS state (red or green). In effect, the inner ellipse disappears under these turbulent conditions. Whenever the VAS state is red and the critical turbulent value is attained, the effectiveness of the VAS can be increased.

4.3 SUMMARY

The VAS is an inherently simple system. Wind velocities near the approach end of a runway are measured, averaged, and compared with a wind criterion (the VAS ellipse), and the results are displayed to an air traffic controller via red or green lights.

The effectiveness of this simple system is shown to vary from a low of 1 percent (at 0300 to 0600 hours in the spring and summer at LAX) to a high of 98 percent (at 1500 hours in August at SFO). Fortuitously, the daily peaks in the effectiveness curves almost always are correlated with the daily peaks in the number of scheduled arrivals at the various airports. The various quantities in Section 3 can be used as part of the input to decide if a VAS should be implemented at the 20 airports which are considered herein.

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